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RIJKSINSTITUUT VOOR VOLKSGEZONDHEID EN MILIEU
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RIVM report 481508 014

Report of the third session of the IMAGE Advisory Board

B. Tinker and the members of the Board.

May 2000

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Abstract

This report summarises the recommendations and suggestions, resulting from the third meeting of the IMAGE-2 Advisory Board. IMAGE-2 is RIVM's global-change model. The main objectives of the meeting were to discuss and review the almost completed version 2.2 of IMAGE, and to advise on required and desirable future developments with respect to the organisation, science and the applications of the IMAGE research. The most important recommendations and suggestions of the report are:

- IMAGE 2.2 and its derived tools are state-of-the-art instruments. IMAGE's comparative advantage is the integration of energy use, land use, climate and impacts. This advantage should be formalised by writing a Mission Statement centred on the objective of the Framework Convention on Climate Change (FCCC).
- Collaboration with national and international institutes, participation in the international global-change research programmes and the contribution to IPCC assessments are important to further develop the model and increase its scientific acceptance.
- The agricultural economy model must be developed in the direction of a land-use economy model so as to better integrate all land-based resources and improve the linkages with the Energy model, TIMER and WorldScan of CPB.
- Climate variability should be included in IMAGE's impact assessments.
- Land-climate interactions are important in defining climate in the future and should be addressed by continuing the linkage with the climate model ECBilt of KNMI.
- Improved regionalisation is desirable.

For more information on the RIVM climate change-projects, please do not hesitate to contact Dr. R. Leemans (leader IMAGE project), RIVM, P.O. Box 1, 3720 BA, Bilthoven, The Netherlands, telephone: +31-30-274 33 77, e-mail: Rik.Leemans@RIVM.nl.

Preface

The Advisory Board convenes regularly to discuss, review and advise on current and future developments and applications related to the integrated assessment model for climate change, IMAGE 2. In the earlier stages of the project (1992 - 1995), the Advisory Board studied IMAGE 2.0 in detail and set the scene for the development of IMAGE 2.1 and its timely applications. The Board's importance lost strength in the second phase of the project (1996-1999), when the policy advisors, who convened in the Delft Dialogue Workshops, adopted a strong advisory role in scenario applications and required developments that were needed to support discussions for the development of the FCCC-Kyoto Protocol. After this, the IMAGE team, began to focus more strongly on a new model version, scientific applications and participation in the development of the IPCC emission scenarios. This recent more-scientific focus required the IMAGE Advisory Board to reconvene. The Board met once again in November 1999; this report not only describes its finding, recommendations and suggestions but sets the stage for new improvements in and development of IMAGE, hopefully, for some years to come.

Acknowledgements

The meeting of the IMAGE Advisory Board was the milestone event for the IMAGE team in 1999 considering the outcome would determine the IMAGE and IMAGE-related research for some years to come.

I would like to thank Leo Meier of the Ministry of Housing, Spatial Planning and the Environment and Bert-Jan Heij of the National Research Programme on Global Air Pollution and Climate Change for their persuasive arguments in convening the Board, and their assistance in defining the scope of the meeting and, providing financial support, without which the meeting could never have been held.

Bernard Tinker chaired the meeting. In our discussions before the meeting he urged me to elaborate the terms of reference of the Board and prepare a detailed background report on research in the progress, envisioned developments and other concrete questions. During the meeting, he was instrumental in guiding the discussions, summarising important topics and finalising the report. I am grateful to him for his efforts and dedication.

The members of the Board delved into the information provided forming a comprehensible picture of our ideas on aims for model development and applications. Their discussions and the resulting recommendations and suggestions helped to identify possible pitfalls and will surely contribute to a much more balanced research programme. I am very appreciative of the time and efforts that all Board members contributed, making the meeting and the report, a success.

The contributions of the IMAGE team to the background document and the presentations at the meeting were indispensable. The team provided insights in the modelling background by increasing the transparency of the model and its assumptions. This openness facilitated effective discussions on the weakest aspects of the model and helped the Board to set priorities for future research. Further, Jeroen van der Sluijs was an effective reporter during the meeting and Bart Strengers assisted in the final editing of the report. I am grateful for the profound endeavours of off all team members in making this meeting a success.

Finally, I would also like to thank the support staff at RIVM-MNV, mentioning especially Jolanda Volle. The staf's organisational talents ensured excellent logistics, facilitated travel and reimbursements, and guaranteed prompt delivery of documents, papers and other information.

Rik Leemans

Project leader

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Samenvatting

De aanbevelingen en suggesties, resulterende van de derde bijeenkomst van de IMAGE Advisory Board (14 t/m 18 november 1999) worden weergegeven in dit rapport. Het doel van de bijeenkomst was het evalueren van de nagenoeg voltooide versie 2.2 van IMAGE, en te adviseren over vereiste en gewenste toekomstige ontwikkelingen met betrekking tot de organisatie van het onderzoek en de wetenschappelijke basis en de toepassingen van het model.

Algemene aanbevelingen (aan) en suggesties (sug)

1. Op het gebied van integratie, met name tussen natuurwetenschappelijke en sociaal-economische onderwerpen en wetenschap en beleid, is IMAGE een koploper. "Global Change" moet het uitgangspunt zijn voor IMAGE 2 onderzoek. Dit zou geformaliseerd moeten worden in een 'Mission Statement', gebaseerd op Artikel 2 van FCCC (aan).
2. Door beperkte middelen is het essentieel om samen te werken, maar het bleef onduidelijk in hoeverre de samenwerkende instituten werden gekozen op basis van een overall plan, of dat ze werden benaderd wanneer de behoefte ontstond. IGBP, WCRP en IHDP gaan samenwerken in "Earth System Modelling". Hieraan kan het IMAGE team bijdragen (sug).
3. IMAGE 2 heeft behoorlijke invloed in de FCCC, maar het is onduidelijk in hoeverre overige gebruikers, zoals Europese programma's, beleidsmakers en geïnteresseerde leken, voldoende bereikt worden. De ontwikkeling van meer regionale modellen voor afzonderlijke landen en Europa is hiervoor te overwegen. Dit zou bijdragen aan Kyoto-protocol beleidskwesties, die vereisen dat wordt gewerkt op een fijnere ruimte-schaal (aan).
4. Vooral beleidsmakers vinden dat inzichten vanuit IMAGE-2 bruikbaarder zouden zijn als werd geprobeerd om vanuit de onderzoeksrichting meer verband te brengen met hun beleidsproblemen (aan). Verder kan onderzocht worden of het COOL Project de efficiëntste manier is om IMAGE-2 te presenteren aan een breder (beleids)publiek (sug).
5. De organisatie van de klimaatonderzoeksprojecten binnen het RIVM is complex. De bij IMAGE betrokken wetenschappers zouden wellicht effectiever en productiever functioneren, als ze deel uit zouden maken van een meer onafhankelijke en herkenbare eenheid binnen het RIVM, met een duidelijke leider (sug).
6. Een verbeterde organisatie van de Advisory Board, waarbij enkele leden voor een bepaalde tijd zitting hebben, zou een meerwaarde hebben voor het RIVM. De Board zou advies geven indien nodig, en iedere twee jaar bijeenkomen voor review en advies (sug).

Belangrijke wetenschappelijke aanbevelingen (aan) en suggesties (sug)

1. De aanbevelingen van de 2^{e} Advisory Board zijn bijna allemaal uitgevoerd. Overgebleven zijn de ontwikkeling van kosten-curven van mitigatiemaatregelen voor landgebruik- en energie-emissies en de voorgestelde verbetering van de koppeling tussen de C- en de N-cyclus. Tenslotte is een validatie- en onzekerheidsanalyse achterwege gebleven. Al deze taken zouden alsnog uitgevoerd moeten worden (aan).
2. Het IMAGE-2 team moet zich bezinnen over mogelijke verbeteringen in modelvalidatie en beschrijving van onzekerheid. Onzekerheidsanalyse is **absoluut** noodzakelijk op alle gebieden waarin IMAGE wordt toegepast. Ter ondersteuning hiervan is deelname in inter-model vergelijkingen zoals AMIP en CMIP gewenst (aan).
3. Het IMAGE-2 team moet rechtstreekser ingaan op actuele beleidsonderwerpen, waarbij de ontwikkeling van de uiterst zinvolle meta-modellen, scanners etc., die het meest relevant en gewaardeerd zijn, moet worden voortgezet (sug).

4. Verwacht wordt dat de beleidsaandacht zal verschuiven naar het bepalen van effecten en aanpassingsmogelijkheden. Hierdoor zal de druk op IMAGE-2 toenemen om betere geografisch expliciete resultaten te genereren. De samenwerking met internationale organisaties IPCC, FCCC, IGBP, WCRP en IHDP moet worden versterkt om IMAGE wetenschappelijk up-to-date te houden, zelfs indien de ontwikkelingen zich bewegen in de richting van een meer lokale schaal (sug).
5. De economische modellering in de landbouwsector is te onafhankelijk van die in de energiesector. Het is wenselijk deze twee beter te integreren. De structuur van het Global Trade Analysis Project (GTAP) zou een goed startpunt kunnen zijn, omdat dit ook de basis is van WorldScan. De ontwikkeling van dit landgebruik-economisch model zou moeten plaatsvinden in een samenwerkingsverband met o.a. CPB, LEI en USDA.(aan).
6. Klimaatvariabiliteit heeft effect op natuurlijke en beheerde ecosystemen en watervoorziening. De invloed van variabiliteit zou diepgaand onderzocht moeten worden (aan).
7. De impactmodules moeten de effecten van veranderingen in jaarlijkse klimaat variabiliteit opnemen, eventueel via geëigende outputs van de gekoppelde GCMs (sug).
8. RIVM ontwikkelt een aparte watermodule, die belangrijke effecten zoals droogte, overstromingen, effecten op irrigatie-systemen en bodemdegradatie simuleert. Het is essentieel dat hierbij de beste internationale partners worden gezocht (aan).
9. Het werk aan C-vastlegging moet worden voortgezet en waar mogelijk geïntensiveerd, omdat juist IMAGE-2 het voordeel heeft van een sterke nadruk op landgebruik (rec).
10. Het huidige zonale klimaat/oceaan model zou moeten worden vervangen door een tweesporen benadering waarin zowel een simpel klimaat/oceaan model als een 3D atmosfeer/oceaan algemeen circulatie model (ECBilt) wordt gebruikt. Beide hebben specifieke toepassingsgebieden (respectievelijk onzekerheidsanalyse en land/klimaat interacties) (rec). Een extra medewerker is nodig voor het ontwikkelen van dit simpele klimaat/oceaan model (sug).
11. Het vermogen van ECBilt om de huidige klimaatvariabiliteit te simuleren moet getest worden. Tevens zou ECBilt moeten participeren in de model vergelijkingsprojecten AMIP and CMIP (rec).

Gedetailleerde aanbevelingen (aan) en suggesties (sug)

1. De huidige methode van het patroonschaling met aerosolen en klimaatverandering moet worden opgegeven. De meer geaccepteerde methode zoals beschreven door Schlesinger et al.[1] zou bij voorkeur gebruikt moeten worden (aan).
2. Het schalen van klimaatvariabiliteit van de grove GCM resolutie naar het IMAGE grid vereist verder onderzoek om te bepalen hoe dit het best gedaan kan worden (aan).
3. Verbeterde regionale effecten van zeespiegelstijging moeten berekend worden (aan).
4. Het is nodig om de kosten en baten van verbeteringen in het atmosferisch chemie model zorgvuldig te evalueren (aan).
5. TIMER kan meer specifieke energiegebruik technologieën bevatten. Kernenergie, duurzame energie en fossiele brandstoffen zouden apart berekend moeten worden (rec).
6. Kapitaalomzetsnelheden in energie productie zoals dit volgt uit snelle veranderingen in CO_2 emissies volgens WorldScan lijken te groot en moeten opnieuw worden bezien (rec).
7. Koolstof-vastleggingstechnologieën zouden gemodelleerd moeten worden (rec).
8. Natuurlijke verstoringen van ecosystemen zouden moeten worden gesimuleerd (sug).
9. Wind- en watererosie moeten een onderdeel worden van een betere regionale landdegradatie module (rec).

[1] Schlesinger et al. (2000). *Technological Forecasting and Social Change*. (in press)

Executive Summary

This summary lists the recommendations and suggestions, which resulted from the third meeting of the IMAGE-2 Advisory Board, 14th - 18th November 1999. The main objectives of the meeting were to discuss and review the validity of the almost completed version 2.2 of IMAGE, and to advise on required and desirable future developments with respect to the organisation, the science and the applications of the IMAGE research.

General recommendations (rec) and suggestions (sug)

1. Global Change should be the target area for IMAGE-2 research. Integration is considered to be the main comparative advantage of IMAGE 2, and in particular its ability to integrate natural science and socio-economic topics and to create linkages with global-change policy issues. This comparative advantage should be formalised by writing a Mission Statement, centred on Article 2 of the FCCC (rec).
2. The shortage of resources makes collaboration essential, but it was not clear whether the collaborators were chosen according to an over-all plan, or were approached as and when a need arose. IGBP, WCRP and IHDP are planning research on Earth System Modelling and this could also become an important collaborative theme for IMAGE 2 (sug).
3. IMAGE-2 has considerable influence in the FCCC, but it is not clear whether all other potential audiences, such as European and national programmes, policy makers, scientists, and interested public, are being addressed equally effectively. In this context, the development of regional impact models for individual countries (e.g., The Netherlands) and Europe should be considered. This would also help to address the Kyoto-Protocol issues, which require finer spatial and temporal scales (rec).
4. Dutch policymakers feel that IMAGE-2 insights can be more useful if the IMAGE-2 staff tries to bring their research development more into line with immediate policy-makers problems (rec). In addition it needs to be considered whether the COOL Project is the most efficient way to present IMAGE 2 to the broader communities (sug).
5. The climate research projects (including IMAGE-2) are organised in a complex structure within RIVM. The scientists involved in IMAGE might function more effectively and be even more productive, if organised as a more unitary and free-standing entity within RIVM, with a single clearly identified leadership (sug).
6. RIVM would get greater value from improved arrangements for the Advisory Board, whereby members should each serve for a set period. Such a Board would give external advice as needed, and meet every two years for review and advice. The membership could then be smaller than at present (sug).

Major scientific recommendations (rec) and suggestions (sug)

1. Recommendations by the 2nd Advisory Board have largely been completed. Remaining matters are the construction of cost curves for relating land use and energy mitigation options. As other research groups have produced such curves, no additional work is now needed for this. The proposed improved linkage of the C and N cycles has not been done, as funding has been short. Finally, a validation and uncertainty analysis has not been carried out yet. All these tasks should be completed, except for the cost curves (rec).
2. The IMAGE team needs to think hard about validation and degrees of uncertainty in their work. Uncertainty analysis is **strongly** needed in all the main areas of operation. Participation in inter-model comparisons such as AMIP and CMIP is desirable (rec).

3. IMAGE-2 staff has to address the concerns of policymakers more directly. The development of meta-models, scanners etc. is very useful, and the most relevant and appreciated ones need to be pursued (sug).
4. As interests are expected to gradually shift from mitigation towards impact assessment and adaptation, IMAGE-2 will be pressed to produce more geographically-specific results. The present close contact with the international bodies IPCC, FCCC, IGBP, WCRP and IHP, must be maintained to keep IMAGE at the cutting edge of scientific developments, even if more of its development moves towards a more local scale (sug).
5. The group appears to resolve economic issues in the agricultural sector separately from those in the energy sector, and it is desirable to integrate them. The structure provided by the Global Trade Analysis Project (GTAP) could be a valuable starting point because it also underlies WorldScan. Collaboration should be explored with CPB, LEI, the USDA's ERS, and others, to develop an integrated land-use economics framework (rec).
6. Inter-annual variations in climate will affect the production of natural and managed vegetation and water supply. These issues should be more thoroughly investigated (rec).
7. The current impact modules should include the effects of interannual climate variability and its changes, and of other appropriate moments simulated by coupled GCMs (sug).
8. RIVM is developing a separate water module, which needs to include important impacts such as droughts, floods, and effects on irrigation systems and soil degradation. It is essential to seek out the best international collaborators for these topics (rec).
9. The work on C-sequestration processes should continued and intensified because the IMAGE team has an advantage due to the strong land-use emphasis of their model (rec).
10. The current zonal-mean climate/ocean model should be replaced by a two-track approach in which both a simple climate/ocean model and a 3D atmosphere/ocean general circulation model (i.e., ECBilt) are used for appropriate purposes (respectively uncertainty and land/climate interactions) (rec). A dedicated person should be allocated to develop the simple climate/ocean model (sug).
11. The ability of ECBilt to simulate the current interannual variability of both the North Atlantic Oscillation and of ENSO should be tested. Also, ECBilt should participate in the model inter-comparison projects, AMIP and CMIP (rec).

Detailed recommendations (rec) and suggestions (sug)

1. The current method of scaling patterns of aerosol-induced climate change should be abandoned. Instead, the more-widely accepted method discussed by Schlesinger et al. (2000) should preferably be used (rec).
2. The downscaling of the interannual climate variability from the coarser GCM resolution to the IMAGE grid requires further consideration of how this can best be done within the constraints of an integrated model (rec).
3. A module for the regional impacts of sea-level rise should be developed (rec).
4. The utility of the atmospheric chemistry model needs to be carefully thought out (rec).
5. The TIMER model should include specific innovative technologies in energy use. Nuclear energy, renewables and fossil fuels should be calculated separately (rec).
6. Capital turnover rates in energy production implied by rapid changes in CO_2 emissions (according to WorldScan) appear to be too high and should be re-evaluated (rec).
7. C-sequestration technologies should be included in energy emission modelling (rec).
8. Effects of natural perturbations on ecosystems could be simulated (sug).
9. A new land degradation routine should separate the calculation of wind and water erosion, as they depend on different components of interannual climate variation (rec).

1. INTRODUCTION

This report summarises the results of the third meeting of the IMAGE-2 Advisory Board between 14th - 18th November 1999.These Advisory Board meetings are organised by the IMAGE team at the National Institute for Public Health and the Environment (RIVM). IMAGE is RIVM's global change model, the acronym standing for 'Integrated Model to Assess the Greenhouse Effect'. The process was started with the First Advisory Board in 1993, and the second in 1995. The institute selects the chairperson and members of the Board on the basis of their expertise, that should be appropriate for current model development and applications. The membership of the third Board is listed in Annex 1, and includes specialists in nearly all the disciplines and topics that IMAGE is involved with. The main objectives of these meetings are to review recent developments and to advise on required and desirable future developments with respect to the organisation, the science and the applications of the IMAGE model and team.

During the period 1995-1998 a series of 'dialogue workshops' were organised as part of the NRP-funded research project 'Further development of IMAGE'. The IMAGE team considered that these dialogue workshops reduced the need to convene the IMAGE Advisory board, because the discussions between the IMAGE team and the FCCC team proposed and considered further work, especially climate change-related policy questions. These dialogue workshops thus provided a degree of continuing external advice. The third meeting of the Advisory Board was planned originally for 1998 but was postponed until 1999 because of institutional and organisational problems.

The detailed purpose and function of the Group is well stated in the Executive Summary of the "Briefing Book" prepared for this Review[2]: "IMAGE-2 is an integrated assessment model for global and regional climate change. The aim of the model is to thoroughly and scientifically simulate policy-relevant issues on climate change. Therefore the model simulates the whole cause-to-effect chain covering emissions from energy and land use, biogeochemical cycles, atmospheric chemistry and circulation, and impacts (of these)".

The Board were given presentations by most of the members of the Group, and an extensive oversight of the Group policy by the Group Leader, Dr. Rik Leemans. We found a highly competent, hardworking and enthusiastic group of scientists, and a dedicated and open leadership. Our general impression of the IMAGE team in general has also been favourable. It deals with important and challenging research subjects that have country, region and global importance. We applaud the position that has been built up by the Group over the last 8 years.

We have structured our Report into General and Scientific sections. The general section deals both with the operation and structure of the Group, and with its position in relation to national and international organisations with policy responsibilities. The Scientific Section deals with the priorities and the practicalities of the research being done and planned for the future.

The Terms of Reference of the Advisory Board are in Annex 2.

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[2] Leemans, R., (Ed.), 1999. History, current activities and future direction of the IMAGE-2 project: The briefing book for the 3rd meeting of the Ad-hoc IMAGE Advisory Board. November 1999. RIVM Report nr. 481508 013. National Institute of Public Health and the Environment, Bilthoven, 108 pp.

2. GENERAL ISSUES

2.1 General strategy

The IMAGE team is in a science field that contains several competitors, and many other organisations that overlap to varying extents with the work that IMAGE is doing. Many of these are collaborators as well as competitors, as often happens in organised science. The possible tasks in this enormous area of intellectual effort (that spreads well outside traditional natural science) are far more numerous than any likely level of funding can support, and prioritisation and selection are essential to ensure focus. This approach should ensure that IMAGE has a strong position in the subject, and that wasteful overlap and repetition is avoided.

As part of this planning, the IMAGE team has to consider the amount of financial support it is likely to gain for this type of work. The subjects are of undoubted global importance, but there is still some doubt concerning the ability of large integrated assessment models to give dependable information about the likelihood of future events. The most important step is to consider where the comparative advantage of IMAGE lies. The Board came to the conclusion that the main advantage was in the widely integrated nature of the IMAGE approach, and in particular its ability to integrate natural science and socio-economic topics and to create linkages with global change policy issues. It covers the many interactions and synergies of the global processes in a way that is still quite rare, and thereby produces output that is more likely to resemble real-world situations than any single-issue approaches. However, the maintenance of this advantage implies that the involved scientists must expand their model to include any process that subsequently appears to have important interactions with those already modelled. This may conflict with the need for focus that is stressed above. A particular example of this at the present is the degree to which IMAGE will include water stress and hydrology in the modelling. The importance of water supply in some parts of the world is now such that this seems to be essential. The IMAGE team aims to meet this type of problem by collaboration.

The team operates from a small West European country (The Netherlands) with a strong science tradition, but with an unusual landscape and land ecology. It does not have the advantage of a very large National Budget (within which its own expenditure would be trivial) or of large areas of uniform climate, soils, land use and ecology where its scenarios could be applied extensively. In the first instance it has therefore stressed its global remit for integrative science. Its particular emphasis on the energy and land-use emissions of greenhouse gases, and the subsequent feedback on to climate, future emissions and other factors appears very appropriate and realistic. The Board considered whether the IMAGE team should be working on Climate Change or on Global change. As Climate Change is really a subset of the latter, it appears best to define Global Change as the target area and thus to maintain a fully integrative approach. In practice, the main difference is that Global Change includes the important ecological and agricultural effects of increased atmospheric carbon dioxide.

The Advisory Board **recommends** that the definition of the comparative advantage of the IMAGE model should be formalised by the writing of a Mission Statement, to indicate as clearly and briefly as possible what the team considers their main tasks to be. We suggest an

approach mainly centred on Article 2 of the FCCC, without accepting that this is all-inclusive. There are an increasing number of systemic coupled ocean-atmosphere General Circulation Models, but few ecosystem-agriculture models linked directly to GCMs, and none that link an energy-economics model to a GCM. Subjects such as food security and land/water needs may be particularly appropriate in a policy context at the present time. IMAGE thus has a distinctive contribution to make in these areas.

2.2 Collaboration

The Advisory Board believes very strongly in the scientific value of external collaboration. The shortage of resources also makes collaboration essential if IMAGE is to cover all the subjects that are justified. As the IMAGE team is so integrative in nature, there is no shortage of potential collaborators. On the other hand, collaboration of any sort uses time and resources, and has to be planned carefully. We were shown very impressive lists of high-quality collaborators, but are not sure whether these were chosen according to any over-all plan, or were approached as and when a need arose. Clearly the collaborators who form part of the geographically dispersed network have been chosen according to a pre-arranged plan. The aim of testing IMAGE's models and results in different localities is a very important objective, and the IMAGE team should therefore always consider whether this network needs to be expanded or strengthened. Bearing in mind the world-wide remit for Global Change, we were a little surprised that IGBP components did not appear more prominently in the presentations. We were pleased to learn that in fact there is extensive collaboration with IGBP projects, and also with LUCC, a joint programme, and that Dr. Leemans sits on several of the Steering Committees. New Joint Core Projects on Agriculture and Earth System Modelling are being planned by IGBP, WCRP and IHDP together, and the Board **suggests** it is likely that this could become an important target theme for IMAGE-2.

2.3 Audience

The immediate scientific audience for IMAGE is the global modelling and integrated assessment community. IMAGE-2 has a high reputation, produced and supported by its strong publishing record. Its input is very much welcomed into the global change community, where its links with the FCCC give it considerable influence. We are not so sure whether all other potential audiences are being addressed equally effectively, and indeed this may be impossible for a group of the IMAGE size. These other groups include the general global science community, European programmes and policymakers, Dutch scientists and policy makers and the Dutch public in general. IMAGE is a Dutch Government-funded entity largely dependent upon the tax-payer. The team should therefore aim for strong generalised support there, and particularly close links with Dutch policy makers. The Board **recommends** that it should consider building regional Impact Models for individual countries (first for the Netherlands) and Europe, to avoid the feeling that its output may be too complex, too aggregated and with too large scales of distance and time to be useful for most individual countries or regions. It should aim for still more exposure in high-quality newspapers, TV and radio broadcasts and other reputable channels of publicity.

2.4 Impact

The impact of IMAGE in the science community is undoubted. It has a strong publication list, and takes part extensively in conferences and meetings. Its output, ideas and concepts are widely discussed. Its impact at the policy maker level is probably more important, and it needs to make sure that this gets maximum attention. The IMAGE team has made a number of actions towards this, such as producing excellent hardback books on the IMAGE model (1994 and 1998) and a softback in 1999. It also produces derived tools for work that is more directly of interest to policy makers, such as meta-models, and scanners, and has arranged the successful series of "Delft meetings". This extension work is now done by a particular project, COOL (Exploring Climate Options for the Long-term). The Board queried whether it is practical to hive off the function of impact generation to a different group, which therefore has to explain and present other peoples work. The Board **suggests** that the IMAGE team should follow up, in discussions with RIVM management, the question of whether the COOL Project is working well, and whether it is the most efficient way to present IMAGE to the outside world. The IMAGE team is very active on this subject, but we were given some evidence that Dutch policymakers feel that it can be still more useful if the IMAGE staff tries to bring their research development more closely into line with the policy-makers problems. The Board **strongly recommends** that all these matters be given careful consideration.

2.5 The IMAGE team structural relationships within RIVM

The climate research projects (including IMAGE) are organised in a complex structure within RIVM, with some curious responsibility relationships, and with staff who are formally members of different entities. A diagram of the various paths of responsibility and accountability is very complicated (c.f. Figure 2.1). The 1st Advisory Board report stressed the importance of the close and daily contact between the members of the IMAGE team. We understand that this still applies, and we applaud it. However, the Board **suggests** that the team might function more effectively, be even more productive, and have a higher profile, if structural relationships could be clarified. This would be appropriate now that IMAGE is so well established and has its own budget line within RIVM. This restructuring would aim at making IMAGE a more unitary and free-standing entity within RIVM. The great majority of the staff who work extensively with IMAGE should formally be part of the team, to ensure continuity and allow more dependable planning, and the team should have a single clearly identified leadership. In this type of applied research it is important that there is good organisation that allows dependable plans to be made.

2.6 IMAGE Advisory Board

The position of the IMAGE Advisory Board is relevant here. At present it meets irregularly, and the membership changes almost completely between the different meetings. This does not give continuity or a good understanding of IMAGE functions and activities. We **strongly suggest** that RIVM would get greater value from a continuing Board, whose members would each serve for a set period. Such a Board would be able to give external advice as needed, and would meet regularly every two years or so for a more organised review. Because members would understand the IMAGE model and applications better, the membership of the Board could probably be smaller than at present.

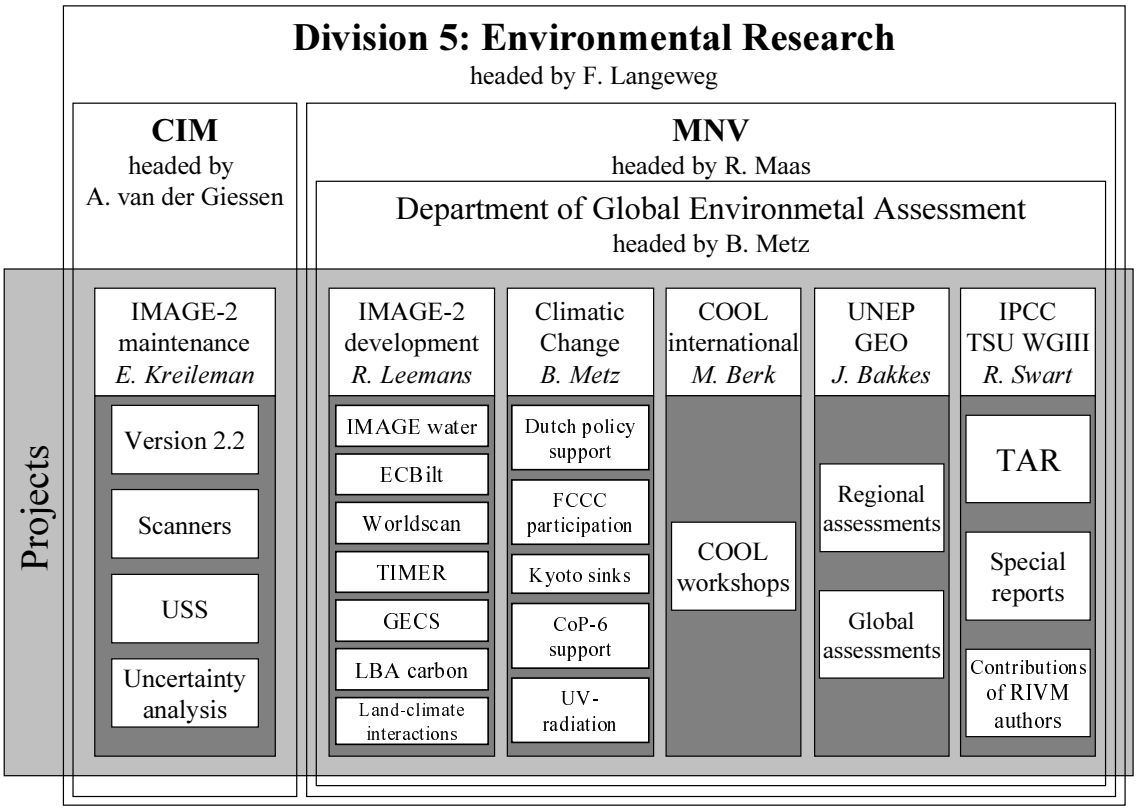

Figure 2-1: Project Structure within RIVM

3. SPECIFIC SCIENTIFIC ISSUES

3.1 The current position of the IMAGE-2 model

IMAGE-2 consists of the three major components; the Energy/Industry system (EIS), the Terrestrial Environment System (TES) and the Atmosphere/Ocean System (AOS). The process of moving from the 2.1 to the more developed IMAGE 2.2 model is well under way. Thus EIS in IMAGE 2.1 model is being converted to TIMER in IMAGE 2.2. This also involves increasing the number of sub-regions of the world to 17. A new version of the Agricultural Economy Model is also under development (see below), and the introduction of internal climate variability in various aspects is planned. Actions recommended by the 2nd Advisory Board have largely been completed, but as the recommendations were not all quantified, we are not absolutely certain whether the IMAGE team has really met the expectation of that Board in all respects. The only matters that are clearly outstanding are the construction of cost curves for relating to land use and energy mitigation options. It appears that other Research Groups produce such curves, so additional investments can be saved for this. Secondly, a full agricultural/economic model dealing with trade and land allocation was to be constructed. Only part of this has been completed so far, and the Board members found some problems in understanding parts of it. The general thrust may need reconsideration. The proposed improved linkage of the C and N cycles has not been done; as funding has been short for this work, but it may now be available. Lastly a validation and uncertainty analysis has not been done yet. The Board encourages the IMAGE team to complete these tasks as soon as possible, except for the cost curves. The overall uncertainty analysis for the whole IMAGE-2 model seems to have the highest priority, as argued below.

3.2 Accuracy and uncertainty

IMAGE staff repeatedly stated that they are not engaged in **prediction**. However, they prepare ‘scenarios’ based on various assumptions and inferences about the future world. Obviously, if the IMAGE model could not tell us anything about the future (or the past), it would be of very limited use. Its application does attempt to make statements about probabilities in the future, and it is therefore in the business of prediction, though not in the sense of mechanistic, precise prediction. The IMAGE team needs to think particularly hard about the importance of uncertainty in this context, because rather little attention was given to uncertainty in the individual presentations to the Board. It also seems unlikely that any form of socio-economic forecasting can be of much value beyond a century ahead. It is evident the many of the statistics that are used to build and run the model must be of dubious accuracy. Some examples of this were presented to the Advisory Board, for example most soil emission data for GHGs are very heterogeneous and average values of any use are difficult to determine on the basis of coarse soil units.

The generalisations that can be made from IMAGE are obviously valuable, but only if one knows what degree of certainty attaches to them, even if only very approximately. The 2nd Board had something to say on this point: “There is no substitute …for identifying and obtaining verification data sets before model development takes place, if only to ensure compatibility between modelled and measured data”. This is indeed the point, but the current

Board was not sure how far the IMAGE team had been successful in this, and for which parts of the model, as forecasting inevitably raises the question of whether control data can be found. Usually this means modelling situations in the past and testing the output against the known data. A Comprehensive Uncertainty Analysis was recommended by the previous Board, and this is due to start soon. The 'briefing document' describes this planned uncertainty analysis, but it is not easy to see from this to what extent the definition of uncertainty is dependent upon subjective or objective procedures. The results of this procedure will need to be transparent and convincing. We **strongly recommend** the need for such studies in all the main areas of operation. As part of this topic, the board **strongly recommends** participation in inter-model comparisons such as AMIP and CMIP, including the testing of the ECBilt-coupled atmosphere/ocean model. There are two staff positions available in 2000 for this work for the NRP-funded project 'Uncertainty analysis IMAGE'. This project strongly focuses on the energy-emissions scenarios, and would need to be extended to the rest of the IMAGE model later.

If these tests are successfully applied to the main IMAGE model, similar procedures should be used for the various derivative models with simpler structures that are now being produced. If the latter are designed to be used by policy-makers, they should be as accurate and dependable as the main IMAGE model. However, the ability to predict short-term catastrophic events must always be problematical. Any statements on who will be winners or losers in future global changes needs particular care.

3.3 The future development of the Group's work in a policy context

To be relevant to public policy questions in the future, IMAGE staff have to be closer to the concerns of policymakers, so that they show a real understanding of what policymakers need. The layout of the model demands greater transparency, for example the linkage between variables should normally be specified in terms of an equation. The Delft dialogues also brought out the need by policymakers for a shorter time scale and a smaller spatial scale than IMAGE-2 was originally designed for. The Safe Landing Analysis was a good example of the outcome of this interaction. The development of derived products, such as metamodels, scanners etc. is very useful, and the most relevant and appreciated ones need to be further developed. The Delft Dialogues have obviously been very useful, but some of the difficult problems in focussing on the real questions in the minds of policy makers, or of suggesting better questions to them, are outlined in Section 8.1.1 of the NRP IMAGE-2 publication. The Advisory Board **suggests** that someone who has been on the staff of a policymaker could be attached to the Group for a year to strengthen this interface

The science and policy views of Global Change will change constantly, and it is essential to position IMAGE so that it is ready for such shifts. One could argue that possession of a fully integrated systems model should allow the IMAGE team to be rather better at foreseeing the next important issue than most other scientists. It seems likely to us that interests will gradually shift from mitigation, as the appropriate policies are gradually put in place, towards impact assessment and adaptation. This suggestion is based on the idea that as the realities of Global and Climate Change become more and more apparent, attention may shift from distant scenarios to the rather closer practical implications of local adaptation. The IMAGE team will then be pressed to produce more and more geographically specific results, with the highest possible degree of reliability, and these can best be produced with smaller, nested modules.

This implies that it may be needed to increase the collaborative links with other bodies, to provide a greater width of disciplinary experience that may be relevant to adaptation, and to give a sounder basis for geographically-specific studies, scenarios and predictions. The present close contact with the international bodies IPCC, FCCC, IGBP, WCRP and IHP, must be maintained to keep IMAGE at the cutting edge of scientific developments at the global level, even if more of its work moves towards a more local scale.

3.4 Future developments of the main model

The model structure of IMAGE 2.2 needs filling out in places, to meet specific needs. The baseline period is now defined as 1970 to 1995, and the world is divided into 19 regions. In some cases future improvement relates to better accuracy and flexibility, as in the AOS model, in others to known gaps, as in agricultural economics models, or expansion to deal with the various methods of carbon sequestration. Some of these issues are discussed in more detail below under Detailed Recommendations. The Board recommends that more attention should be paid to the transparency of the various submodels, to allow a better perception of what happens in a simulation. It also recommends that the models be scanned to ensure that there is internal consistency in the assumptions that are implicit in the various submodels, and that may easily be lost sight of in such a complex system.

3.5 Future developments of the agriculture/energy component

The Advisory Board believes that the IMAGE team knows what problems need to be resolved in a new Agricultural Economy Model (recently called the Land Demand Model). In the present model, land intensities are poor proxies for food prices, international trade in agricultural commodities is treated as a residual, and biofuel production is given priority over food production when determining land use. IMAGE staff are also aware of the key scientific issues, namely climate and weather variability, irrigation and competing uses of water resources, and land degradation. A number of steps have been taken towards the inclusion of these issues into IMAGE 2.2. However, alternative models, such as the US Department of Agriculture's Future Agricultural Resources Model (FARM), could be helpful in resolving the economic problems. These issues must be incorporated into IMAGE, whilst maintaining its compatibility with WorldScan, which currently provides the linkage with the world economy in the most recent scenario applications.

Nevertheless, the IMAGE team appears to resolve economic issues in the agricultural sector separately from those in the energy sector, but it is desirable to integrate the agricultural and energy sectors within one economic model. This would enable simultaneous global simulations of production, trade, and consumption of energy and agricultural commodities. The economic model also should be able to simulate competition for land and water resources by the agricultural, forestry, bio-energy, and other sectors.

One way to proceed is to incorporate an existing FARM-like economic database and modelling framework into IMAGE. FARM, like WorldScan, is developed from information provided by the Global Trade Analysis Project (GTAP) at Purdue University. This would enable IMAGE to conduct analyses in both physical and monetary units while remaining consistent with WorldScan and its databases within IMAGE. An added benefit for IMAGE

would be greater flexibility in regional desegregation, as GTAP now has separate data for 45 regions of the world. The IMAGE team should explore the possibility of collaborating with The Netherlands Bureau for Economic Policy Analysis, (CPB), the Netherlands Agricultural Economics Research Institute (LEI), the USDA's Economic Research Service, and others, to develop an Farm-like modelling framework compatible with IMAGE during the year 2000.

Issues that could be resolved include 1) simulating agricultural production and trade with prices rather than with land intensities, 2) realistically simulating international trade in agricultural and energy commodities, 3) simulating competition for land by agriculture and other sectors (especially forestry and bio-energy), 4) simulating competition for water by irrigators and other users of water resources, and 5) simulating land degradation. These effects could be simulated both with and without weather variability.

The Board therefore strongly **recommends** that the agricultural, terrestrial land surface and energy components of IMAGE should be integrated through a comprehensive economic framework. This economic framework should be able to simulate competition for land and water resources in all major sectors. This would help to eliminate inconsistencies in calculating changes in terrestrial land use, greenhouse gas emissions, and other entities. It would also facilitate policy analyses by providing the means for simulating taxes or subsidies and reporting results in terms of economic costs and benefits as well as in terms of physical units.

3.6 Interannual climate variation and its effects

The Board was pleased to note that the IMAGE team plan to add interannual climate variation to their models, as this will contribute greatly to the realism of the output. The following issues will be benefited by this extension

Interannual variations in temperature, radiation and precipitation will affect net primary production of vegetation, economic yield of crops, evapotranspiration and water supplies The existing relationships and models for this purpose are not highly accurate, and research may be necessary to improve them. It follows that these transient changes in production and water supplies can induce wide changes in the price of foodstuff, loss of food security, poverty and starvation in some regions, whereas others may enjoy a productive year. The Board recommend that the IMAGE team should investigate these issues more thoroughly, in collaboration with experts on food security, such as the International Food Policy Research Institute (IFPRI).

If the IMAGE team can determine the relationship between interannual variations in weather and Net Plant Productivity, this would permit calculation of interannual variations in NPP at a global scale, and its effects on the global carbon cycle. This could then be compared with oceanographic and atmospheric carbon cycle measurements. This might permit the calculation of Net Biome Productivity also. (The NBP is the land carbon balance including various long-term sinks.) The Board also **recommends** that the team investigates the possibility of modifying the model to calculate the discrimination of isotopes of carbon and oxygen by methods that are analogous to those currently used in studies of ocean and atmosphere carbon cycle dynamics. This might be used to validate IMAGE carbon cycle dynamics by comparing these calculated isotope ratios with known seasonal and geographic

distributions of the ratios. Interannual climate variation also affects the impacts of droughts, and wind and water erosion, and the probability of wildfires.

This focus on interannual climate variability will also demand changes in the AOS modelling. The current impact modules of IMAGE should be amended to include the effects of interannual climate variability and its changes, and of other appropriate moments simulated by coupled atmosphere/ocean GCMs. The mean climate changes simulated by GCMs need to be scaled, using the global-mean temperature, and this should also be done for the interannual climate variability and other appropriate statistics of the GCM's simulated frequency distributions.

3.7 Water- and soil-related issues

Natural resources management will be of steadily increasing importance during global change, because of the probable changes in the world water cycle. There is general agreement that water use will be one of the main political issues in the next century, at least in some parts of the world. The interaction with climate change may produce devastating consequences. Precipitation is difficult to predict quantitatively in a GCM on a coarse grid cell of several hundreds square kilometres during climate change, and evapotranspiration even more so.

RIVM is developing a separate water module to simulate these effects, including a water routing scheme and various hydrological processes. So far it has not been taken properly into account in impact generation. It seems important that this is done, to include droughts, floods, effects on irrigation systems, and on soil degradation. The last includes soil erosion, soil salinization and desertification. All these are difficult to model because so many of the processes are highly site-specific and non-linear. Existing erosion models in particular are at present very simple, but the Board considers that the IMAGE team must continue to work on these systems because of their importance for policy-makers. It is essential to seek out the best international collaborators in these topics. The International Water Management Institute in Sri Lanka is now developing total water balances on a country by country basis, and relating the results to land cover and crop development as determined by remote sensing; this could usefully be compared with IMAGE's results. The Board **recommends** that the IMAGE team continue to develop simulation of water demand and supply and land degradation, using the best collaborators it can find among specialists in these areas. These topics are important for policymakers now, and are likely to become more so in the future. They also have impacts on ecosystem change and carbon sequestration.

3.8 Sequestration of carbon dioxide

The IMAGE team considers the addition of C-sequestration processes to the model as an important activity, as it is relevant to the Kyoto Protocol. Some of the potential methods are highly technological, such as storing carbon dioxide in aquifers, the deep ocean or exhausted gas fields. The team will simply have to add these in as they develop, as it seems very doubtful whether their success or magnitude can be predicted now. The other type of sequestration is in vegetation and soils (Article 3.3 and 3.4 of the Kyoto protocol). This can obviously happen as a natural process, and the uncertainty lies in whether it can be

significantly increased by alterations in land cover or management, bearing in mind all the other demands on land and the possibility of land degradation. It is closely connected to the other land use/vegetation issues in the IMAGE model, and it appears logical to deal with it as part of these. Currently the IMAGE team already plans to implement this aspect of the Kyoto protocol as part of EU and NRP funded projects. The Board **recommends** that this work should continue and where possible should be intensified because the IMAGE team already has an advantage due to the strong land-use emphasis of their model.

3.9 Climate/ocean coupled models

In agreement with the 2nd Advisory Board, the present Board **recommends** that the IMAGE team pursue a two-track approach in which both a simple one-dimensional climate/ocean model and a 3D atmosphere/ocean general circulation model are used for appropriate purposes. Thus difficulties have been encountered in scaling the patterns of climate change simulated by GCM's when using the latitudinal temperatures produced with IMAGE's current zonal-mean climate/ocean model. It therefore believes that this model should be replaced by a simple one-dimensional climate/ocean model for these purposes. This simple model is also more appropriate for scaling both mean climate changes simulated by GCM's and also their interannual variability and other moment statistics (e.g. kurtosis) from their frequency distribution of monthly seasonal climate anomalies. A dedicated person should be allocated to develop this simple climate/ocean model, and should follow the methods given in the IPCC Third Assessment Report, particularly in terms of the radiative forcing calculation.

The Board **strongly recommends** that work should be done on the ECBilt coupled atmosphere/ocean GCM to test and improve its performance and link or incorporate it into IMAGE. The ability of ECBilt to simulate the current interannual variability of both the North Atlantic Oscillation and of ENSO should be tested in order to obtain fair agreement with observed values. This is a hard test, since large GCM's have problems with this, but the performance of ECBilt in this test will give useful information. The ECBilt coupled model, and its individual component atmosphere and ocean models, should participate in the model intercomparison projects, AMIP and CMIP. The ECBilt coupled model should initially be used, uncoupled to IMAGE, to simulate different radiative forcing scenarios, and its results should be compared with those of other GCM's. Finally, the ability of the coupled atmosphere/ocean model to simulate changes in the thermohaline circulation should be determined. The results should be compared with those of other coupled atmosphere/ocean GCM's. The coupling between ECBilt and IMAGE should in the longer term be used to analyse the interactions and feedbacks between the biosphere and the atmosphere consistently.

The purpose of the coupling of IMAGE with ECBilt is not only to improve the climate-change scenario development as above, but also to analyse the interactions between the land surface and the climate system. This topic has been identified as important by the forthcoming third assessment report of IPCC. A simple climate model or scenario analysis cannot adequately address this aspect, and a more process-based model like ECBilt is required. The methods of coupling ECBilt to IMAGE, either one-way and two way, should be investigated.

4. DETAILED RECOMMENDATIONS

4.1 For the Atmosphere Ocean System

The Board **recommends** that the following actions be undertaken:

a) The current method of scaling patterns of aerosol-induced climate change using the global-mean temperature, as is done for the patterns of GHG-induced temperature changes, should be abandoned. Instead these individual aerosol and GHG patterns should be separately scaled using the individual global-mean temperature changes induced by regional aerosol forcing and global GHG forcing respectively. This method was pioneered by Wigley, and is discussed in a paper by Schlesinger et al. (2000) that is in press in *Technological Forecasting and Social Change*.

b) The downscaling of the interannual climate variability (and other appropriate moment statistics of the monthly anomaly distributions) from the 300-500 km grid resolution of the GCMs to the 0.5 degree by 0.5 degree grid size of the IMAGE model is an important step. Further consideration is needed of how this can best be done within the constraints of an integrated model.

c) A module for the regional impacts of GHG-induced sea-level rise should be developed for IMAGE.

d) The role and utility of the atmospheric chemistry model in IMAGE needs to be carefully thought out.

e) Where appropriate, the team should calculate the propagation through the IMAGE model of the key uncertainties of the climate system

4.2 For the Terrestrial Environment System and the Energy Industry System

The Board **recommends** that the following actions should be undertaken:

a) The TIMER model includes technological evolution but not specific innovative technologies in energy use. The coarse aggregation of emissions does not permit calculation of impacts by changing technology (e.g., distinguishing differences in emissions from the same type of industrial sources that vary in size). The Board **recommends** that the IMAGE team maintain a careful watch for such changes.

b) The Board suspects that capital turnover rates in energy production implied by rapid changes in CO2 emissions shown in Mr. Bollen's presentation on the linkage with WorldScan appear to be too high and should be re-evaluated during further development of energy modelling.

c) Post-combustion capture of carbon by developing sequestration technologies should be included in energy emission modelling.

d) Nuclear energy, renewable (solar, wind) and fossil fuels should be calculated separately. It appears illogical to aggregate nuclear energy (that uses finite resources and produces toxic waste) with truly renewable energy sources such as solar heating, water power or wind farms.

e) Effects of natural perturbations (wildfire, drought, etc.) on ecosystems could be simulated. This will be more easily accomplished when inter-annual climate variability is included in IMAGE, but short- term local disturbances will always be difficult to handle, and the Board recommends that the IMAGE team considers what action it should take on this topic.

f) The Board **suggests** that calculations of carbon sequestered by below-ground deposition should include the increasing allocation of carbon below-ground by plants growing under increasing atmospheric CO2 concentrations. This process is still being investigated, but it appears to occur consistently. It can arise both from greater total production of dry matter, but also from higher percentage allocation to roots, storage organs and exudates.

g) The Kyoto Protocol (Articles 3.3, 3.4) uses fine spatial and temporal scales that make application of IMAGE difficult, though it is highly desirable. One way of bringing IMAGE to bear on this issue is to nest new individual country models within IMAGE models, with the IMAGE modellers providing the open linkages for individual country modellers to utilise in their own efforts. The Board **strongly recommends** that the IMAGE team should test this, because the Kyoto Protocol is very important, and likely to continue for many years. The solution could be to develop an interface between IMAGE and any individual country, much as mesoscale climate models are nested within GCMs, starting with the Netherlands.

h) The Board **recommends** that carbon and nitrogen cycles in the IMAGE model should be linked, as the IMAGE team is already working towards. These cycles are strongly interdependent globally, regionally and locally, and carbon fluxes are especially difficult to calculate in industrialised regions where the majority of nitrogen compounds reaching soils are of anthropogenic origin. The accuracy of the IMAGE carbon cycle output is likely to be strongly enhanced by this.

i) The addition of inter-annual climate variability will permit an important improvement in the new land degradation routines, i.e. separate calculation of wind and water erosion, as they depend on different components of inter-annual climate variation.

5. QUESTIONS TO THE ADVISORY BOARD

Four specific questions were posed by Dr. Leemans to the Board, which we attempt to answer briefly here.

What are the key scientific and policy questions?
Accuracy and robustness of integrated models, especially at small distance scales and short times.
Sufficiently accurate estimations of carbon sequestration processes to determine if they can mitigate carbon dioxide increase. to a worthwhile extent.
Can integrated models reliably forecast the best adaptations for various impact scenarios? Are these forecasts any better than using existing scientific, economic, sociological and technical knowledge directly (i.e. is what value is added by the model)?

How can the balance between model, derived tools and other application components be maintained and improved?
The robustness and certainty of the model is fundamental. The amount of effort on derived tools should be determined largely by the consumer need and appreciation.

How can the structure and the results be communicated better (which indicators, USS or otherwise)?
By putting more time into the education of the users of the model.

Should more issues be incorporated, *versus* a more detailed climate model?
Greater detail should only be added if it produces greater certainty. The 2nd Advisory Board noted that the ocean sub-model needed little further development, because of the existence of more sophisticated ocean models. Certain world-wide processes may have such a large effect that they should be included. These could include major health changes (AIDS); changes in agriculture and food security resulting from genetically manipulated crops, general changes in national wealth and economics. However, we think that the IMAGE team should be cautious about adding such further issues unless the case for including them is very strong.

6. CONCLUSION

The Advisory Board believes that the IMAGE team is headed in the right direction, and the recommendations that are discussed here are intended to assist this. The overall thrust of our views is that the Group needs to strengthen the basic model where there are clear deficiencies, determine the certainty of its output, and give great attention to the uses of this output, especially by policymakers. The Board is conscious of the width and range of the work done by the IMAGE team, and also of the fact that the Board's own recommendations may suggest a still wider programme of work in some cases. Nothing that is said here should detract from the need to assess carefully the total dependable resources available, and to determine priority projects in relation to these.

The Board thanks the management and staff of RIVM for the help and support they have given to it during the Review.

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Annex 2 Terms of Reference for the IMAGE advisory Board

The objectives of the IMAGE model

Scientific and policy questions about the global system of society, biosphere and climate are by nature multi-disciplinary, and have local, regional and global aspects. The general objective of the IMAGE 2 model is to fill in some multi-disciplinary gaps in global change research by providing a disciplinary and geographic overview of the society-biosphere-climate system.

The scientific goals of the IMAGE 2.1 model are:
- To provide insight into the relative importance of different linkages in the society- biosphere-climate system;
- To investigate the relative strengths of different feedbacks, interactions and synergies in this system;
- To estimate the most important sources of uncertainty in such a linked system; and
- To help identify gaps in knowledge about the system in order to help set the agenda for climate change research.

The policy-related goals of the model are:
- To link important scientific and policy aspects of global climate change in a geographically-explicit manner in order to assist decision making;
- To provide a dynamic and long-term perspective about the consequences of climate change;
- To provide insight into the systemic interactions and side effects of various policy measures;
- To investigate the influence of economic trends and technological development on climate change and its impacts; and
- To provide a quantitative basis for analysing the costs and benefits of various measures (including preventative and adaptive measures) to address climate change.

These objectives have steered the design and development of the model, as well as its uses. The design of IMAGE 2 has also been strongly influenced by discussions with both scientists and policy makers. Their concrete recommendations about model design were collected at two major international meetings specifically organised to review preliminary versions of the IMAGE 2 model. Another important vehicle for identifying applications of the model was the so-called "Delft Process", which was a series of meetings between global modellers and policy makers concerned with the climate negotiations. Through these meetings the IMAGE 2 model was applied to questions of interest to the negotiations leading up to the Kyoto Climate Summit of December, 1997. This series of meeting with active IMAGE team participation currently continues within the NRP-funded COOL project.

Objectives of the IMAGE Advisory Board

The purpose of the IMAGE advisory Board is to evaluate recently developed modules and their implementations in the IMAGE 2 model framework, to suggests required and desired improvements, and to advise on (the priorities) for possible future developments and applications.

The IMAGE Advisory Board should review the (proposed) model developments and applications on basis of scientifically acceptable approaches, state-of-the-art understanding of processes and their dynamics and a balanced contribution of the required disciplines. Besides these important scientific boundary conditions, the Board should give guidance on policy-relevant applications, which are required to address (upcoming) issues resulting from the FCCC-negotiations or IPCC assessments. Such guidance should assist in prioritising future model development.

Members of the IMAGE Advisory Board

The IMAGE advisory Board is an ad-hoc group which gathers irregularly depending on new model developments, the substance of research proposals or planned contributions to the IPCC and FCCC processes.
A chairperson leads the Board. This person is proposed and approached by the project leader of IMAGE after consultation with and approval by the major funding agencies, such as the Ministry of Housing, Physical Planning (Ministry of VROM) and the Dutch National Research Programme "Global Air Pollution and Climate Change" (NRP). The chairperson should be a scientist with an excellent reputation in one of the disciplines relevant to IMAGE 2. He/she should further have experience in evaluating and advising on internationally oriented research projects.
Additional experts are invited to participate on the board. They will be selected on behalf of their expertise and scientific merits. The composition of the Board can change depending on the topics that are discussed. Generally, up to ten experts for the Energy-Industry System, Terrestrial Environment System en the Atmosphere Ocean System will be invited. Besides covering the different components, these experts should focus on the causal chain 'driving forces, emissions, systemic processes and impacts'. Therefore, the experts should be disciplinary specialists but with a broad view on global change. IMAGE is a so-called integrated assessment model or earth system model covering many disciplinary fields. Therefore, the Board members should have a positive attitude towards this kind of comprehensive modelling.
To guide the discussions towards required policy applications, up to five participants from the user community (i.e. persons involved in the FCCC negotiations, Ministry of VROM or EU policy makers) will be invited.
The development of IMAGE is not solely done at RIVM. Several collaborative organisations and institute participate in developing specific components or applications. The are the Centre for Climate Research (CKO: IMAU-UU, KNMI & RIVM), the International Research School for Co-operation on Oceanic, Atmospheric and Climate Change studies (CAOCh: CKO & MPIs), the Centre for Climate Change and the Biosphere (CCB: LUW & LNV-DLO institutes) and the European Partnership on Research in Integrated Modelling of the Environment (EuroPRIME: RIVM, PIK, University of Kassel, CIRED and ECU). If necessary, participant of these institutes will be invited to participate.

Tasks

The Chairperson:

The tasks of the chairperson are to develop, in close collaboration with the project leader, the programme of the advisory board meeting. During the meeting, the chair governs and concludes the meeting. After the meeting he/she delivers a concise report with all the findings, suggestions and conclusions of the Advisory Board. The board will draft an outline of the report during the last session, after which the Chair will prepare a comprehensive draft version. This version will be circulated for comments among all participants. The chair incorporates the comments and submits the final version to the project leader for publication.

The board members:

The board members will contribute with their expertise and experience in order to review recent developments of the IMAGE model. In this review, they will highlight scientific shortcomings and credibility. They will further assist in prioritising future research and advice on the most likely, successful applications in light of FCCC and other applications. After the board meeting, member will comments on the draft report written by the chairperson.

The IMAGE team and their collaborators:

The IMAGE team will prepare discussions on and document, the new developments of the model and present them orally during the board meeting. Each presentation will discuss the

recent developments, highlight problems and present possible future directions. The IMAGE information will further be prepared in a comprehensive briefing book.

Meetings

The IMAGE advisory Board meets at an irregular basis. The logistics of the meeting will be supported by the secretariat of RIVM-MNV. The costs for the meeting will be taken from the IMAGE project budget. Participants will be reimbursed for their travel costs (economy fare) and local expenses. The chair will get a small consultancy fee to facilitate his work and efforts.
The meeting will cover three consecutive days. The preliminary programme of the meeting will be defined by the project leader and discussed with the chair. The last afternoon of the meeting will be dedicated to discussion of the Advisory Board to draft the conclusions and recommendations of the meeting. If necessary, the project leader could be asked to give advice during this process but the IMAGE team and their collaborators will not participate in this session.

Outcome

Each meeting of the IMAGE advisory board will result in a short document, which will be published as a RIVM report, stating the findings, conclusions and recommendations.