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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

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List of Acronyms

AET	Actual Evapotranspiration
AIRCLIM	A EU project, which combines the impacts of acidification and climate change
AOS	Atmosphere-Ocean System, a model component of IMAGE 2
A-TEAM	Advanced Terrestrial Ecosystem Analysis and Modelling
CCB	Research Centre for Climate Change and the Biosphere
CDM	Clean Development Mechanism
CIRED	Centre International de Recherche sur l'Environment et le Dévelopment
CKO	Dutch Centre for Climate Research
COOL	Exploring Climate Options for the long-term
CoP	Conference of Parties
CPB	The CPB Netherlands' Bureau for Economic Policy Analysis
DLO	Dutch Agricultural Research Institutes
DSS	Decision Support Systems
ECBilt	The simplified GCM-climate model, developed by KNMI , de Bilt.
EDGAR	Emission Database for Global Atmospheric Research
EIS	Energy Industry System, a model component of IMAGE 2
EMF	Energy Modelling Forum, Stanford University
EU	European Union
EuroPRIME	European partnership for Research on Integrated modelling of the Environment
FCCC	Framework Convention on Climate Change
FAO	UN Food and Agriculture Organisation
FAIR	Framework to Assess International Regimes for Burden Sharing
GCM	General Circulation Model (i.e. the most advanced climate model)
GECS	Greenhouse Gas Emissions Control Strategies
GEO	UNEP's Global Environment Outlook
GHG	Greenhouse gas
HYDE	The Hundred Year Database for the Environment
IGBP	The international Geosphere-Biosphere Programme
IHDP	The international Human Dimension Programme of Global Change
IPCC	Intergovernmental Panel on Climate Change
IMAGE	Integrated Model to Assess the Greenhouse Effect
IMAU	Institute for Marine and Atmospheric Research of Utrecht University
ISRIC	International Soil Reference and Information Centre
ISS	Interactive Scenario Scanner
IVM	Institute of Environmental Studies, Free University of Amsterdam

JI	Joint Implementation
KNMI	Royal Dutch Meteorological Institute
LBA	Large Biosphere project in the Amazon
MB	Milieubalans(Dutch State-of-the-Environment Report)
MV	Milieuverkenning (Dutch Environment Outlook Report)
NRP (or NOP)	Dutch National Research Programme on Global Air Pollution and Climate Change
PET	Potential Evapotranspiraiton
PIK	Potsdam Institute for Climate Impact Research, Potsdam, Germany
POET	Precursors of Ozone and their Effects in the Troposphere
SRES	IPCC's Special Report of Emission Scenarios
TAR	IPCC's Third Assessment Report
TES	Terrestrial Environment System, a model component of IMAGE 2
USS	User Support System
WURC	Wageningen University and Research Centre
WUSS	WorldScan User Support System
SLA	Safe Landing Analysis
UN-CSD	United Nations Commission on Sustainable Development
UU	Utrecht University
UNEP	United Nations Environment Programme
VROM	Dutch Ministry of Housing, Physical Planning and the Environment
WURC	Wageningen University and Research Centre

Abstract

This report presents background material for the third meeting of the Ad-hoc IMAGE-2 Advisory Board. This Board reviews recent developments and applications and give advice on potential future directions of the IMAGE-related climate-change projects at RIVM. The aim of this report is to give an overview of the past achievements of the IMAGE-2 team and an outlook to future plans. Objectives and history of the project are summarised. The institutional imbedding of the IMAGE-2 project and its relations to other projects are presented and discussed. The recommendations and suggestions of the second meeting of the advisory Board are summarised. It is concluded that most recommendations were implemented over the last years as part of the NRP-funded project 'The IMAGE-2 Model: Policy and Scientific Analysis'.

Ongoing activities are then presented and the future research strategy is outlined. Summaries are given of all the presentations during this meeting of the advisory board. These presentations and following discussions should assists the Board in preparing their advice. Appendices are provided with additional material covering the programme, an participant list, planned personnel resources of the project in 2000 and a short description of all related projects that are part of further IMAGE-2 development and/or contribute to its applications.

The report concludes with questions and issues, which should be addressed by the Advisory Board.

Samenvatting

Dit rapport bevat het achtergrond materiaal voor de derde bijeenkomst van de ad-hoc IMAGE 2 adviesraad. Deze adviesraad beoordeelt recente versies en toepassingen van het IMAGE-2 model en geeft aanbevelingen voor mogelijke toekomstige ontwikkelingen van IMAGE 2 en gerelateerde projecten. Het doel van dit rapport is om een overzicht te geven van de bereikte prestaties van het IMAGE-2 team en om de huidige en voorgenomen activiteiten en projecten te presenteren.

Het rapport geeft allereerst de doelstellingen en een korte geschiedenis van het project. Daarna wordt de huidige institutionele inbedding en de relatie met de andere projecten van het RIVM aangaande klimaatverandering bediscussieert. De tweede bijeenkomst van de adviesraad leidden tot vele aanbevelingen en suggesties. Deze zijn kort samengevat in het rapport. Het advies van de raad heeft sterk bijgedragen tot het ontwikkelen en uitvoeren van het NOP-project 'The IMAGE-2 Model: Policy and Scientific Analysis' en is essentieel geweest bij het tot stand komen van IMAGE 2.1 and toepassingen daarvan. Ook huidige en geplande activiteiten worden gepresenteerd. Samenvattingen van alle IMAGE-2 presentaties gedurende deze bijeenkomst zijn opgenomen. Het rapport bevat verschillende appendices met additionele informatie over het programma en de deelnemerslijst, de voor 2000 geplande personele capaciteit, en een korte beschrijving van aan IMAGE 2 gelieerde projecten. Deze projecten dragen bij aan de verdere ontwikkeling of behelzen een nieuwe toepassing van het model.

De diversiteit aan gewenste beleidstoepassingen, de beschikbare capaciteit en de reeds aangegane verplichtingen leidt tot een voorlopige IMAGE onderzoeksstrategie. Een overzicht hiervan wordt gepresenteerd, zodat die door de adviesraad kan worden bediscussieerd. Het rapport eindigt met specifieke vragen en algemene kwesties die tijdens de derde bijeenkomst van de adviesraad behandeld moeten worden.

Acknowledgements

The content of this briefing report was discussed during a visit of the Chair of the Advisory Board, Dr. Bernard Tinker. His eagerness to obtain all possible information on the research, the model, the institute and the intended audiences helped to structure this report and to write it in a timely and efficient manner. Joe Alcamo, Bert Metz, Bert Jan Heij and Jan Bakkes provided welcome comments on earlier drafts and checked some of the qualitative data provided in the report.

The IMAGE-2 team worked hard to provide abstracts in time and discussed all presentations in detail before the meeting. Their ambition is certainly to provide a transparent overview of the model and its applications so that the Advisory Board can develop well-founded recommendations and suggestions for desirable future research directions and innovative and timely applications. I really appreciated their dedication and will to make this meeting a success.

I would finally like to thank Leo Meyer of the Ministry of VROM and Bert-Jan Heij of the Dutch National Research Programme on Global Air Pollution and Climate Change for their financial assistance to organise this for IMAGE-2 research important meeting.

1. Introduction

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 IMAGE-2 model (IMAGE means Integrated Model to Assess the Greenhouse effect; Alcamo, 1994, Alcamo *et al.*, 1998 and Leemans *et al.*, 1998; Figure 1) has been developed at and applied by RIVM over the last decade to address these global-change questions. The general aim 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.

More specifically, the scientific goals of the IMAGE-2 model are:

- To provide insight into the dynamic responses of the society- biosphere-climate system to environmental change;
- To investigate the relative strengths of different interactions, feedbacks 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;

while the policy-related goals of the model are:

- To link scientific understanding of global climate change to policy issues 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.

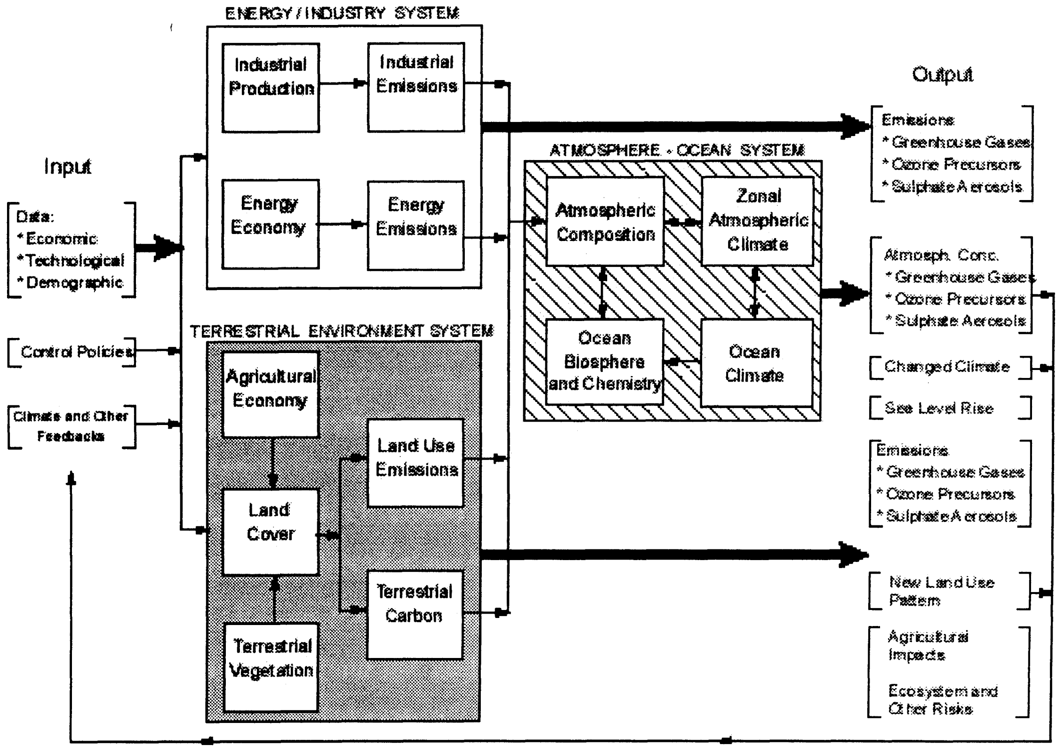

Figure 1 Flow diagram of IMAGE 2

These objectives have steered the design and development of the IMAGE-2 model, as well as its applications.

In order to maintain a high scientific standard and to keep model developments relevant and timely for policy support, an Advisory Board was installed. The main purpose of this IMAGE-2 Advisory Board[1] is to evaluate recently developed modules and their implementation in the IMAGE-2 model framework, to suggest required and desired improvements, and to advise on (the priorities) for possible future developments and applications. Up to now, two meetings of the Advisory Board have been held (Hordijk, 1993; Solomon, 1994). The recommendations of these meetings of the Board about model design and applications were used to concretely guide the developments and applications of IMAGE 2.1 within the framework of the IMAGE-2 project funded by the Dutch National Research Programme on Global Air Pollution and Climate Change (NRP). This project was executed over the period 1995-1999 and reported by Leemans and Kreileman (1999) and many other scientific and popular publications. This NRP-funded project is now finished and it has led to:

[1] Ad-hoc because it meets irregularly and membership can change according to needs and availability.

1. further development of the highly detailed IMAGE-2 model;
2. a large array of different scenarios;
3. a comprehensive User Support System (USS);
4. an effective dialogue between the IMAGE-2 team and Framework Convention on Climate Change (FCCC) policymakers; and
5. several derived interactive tools to address specific policy questions.

The IMAGE-2 project has also changed its structure because the IMAGE-2 model has become an accepted tool for several of RIVM's main national products, such as the annual state-of-the-environment reports and the environment outlooks, and some international assessments in which RIVM participates (e.g. European Union (EU)'s and United Nations Environment programme (UNEP)'s environment outlooks). Further, major applications with respect to FCCC are now imbedded in closely related projects. IMAGE-2 model maintenance, development and applications are thus structurally separated in different projects, each with a different leader (see chapter 3). This requires a good communication between project leaders and well-defined responsibilities.

Besides these structural changes in the organisation of the project over the last years, the policy needs have been changed. IMAGE 2 has been instrumental in highlighting important global change issues for scientific and policy discussions leading to the Kyoto Protocol of FCCC. Currently the FCCC policy focus has shifted strongly to flexible instruments to effectively reduce emissions, evaluation of sequestration potential and defining impacts and potential adaptation, especially in developing countries. These issues cannot (yet) adequately be covered by IMAGE 2. Over the next years, when the adequacy of the emission reductions of the first commitment period will be evaluated and the discussion on next steps during the second period start, the focus is expected to change again towards a better quantification of the long-term issues as specified by Article 2[2].

Together these changes make it appropriate to again convene the Ad-hoc IMAGE-2 Advisory Board and review the planned activities and help to steer future model developments and applications. This meeting is planned for November 15-17, 1999 in the

[2] The ultimate objective of FCCC (Article 2) is: ".... stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system..."

Ernst Sillem Hoeve in Bilthoven/Den Dolder. The programme, participants, and additional background materials are presented in respectively Appendices A, B and C. This report, together with the final NRP report (Leemans and Kreileman, 1999) forms the background information for this meeting.

First, the report summarises the findings and recommendations of the second Advisory Board meeting and discusses how these were implemented and executed (Chapter 2). Then, the institutional imbedding of the IMAGE-2 and related projects is presented (Chapter 3). In Chapter 4 the current activities and planned future developments are listed and discussed. Summaries of the presentations by the IMAGE-2 team are given in Chapter 5. Finally, we have assembled a (not yet exhaustive) list with questions and issues on which we would like to obtain the view of the Advisory Board (Chapter 6). This report and the presentations of and discussions with the IMAGE-2 team should facilitate a balanced advise of the Advisory Board. Their final report with findings and recommendation will be published soon after the meeting, in the RIVM-report series.

2. Summary of the suggestions by the 2nd IMAGE-2 Advisory Board

The 2nd IMAGE-2 Advisory Board was held 22-24 June 1994 (Solomon, 1994). The 2nd Advisory Board focused on the scientific merits and possible applications. FCCC had just been ratified and the negotiations of the Conference of Parties (CoP) started. Its recommendations helped to draft the proposal to the Dutch National Research Programme "Global Air Pollution and Climate Change" (NRP). With only slight modifications, this research proposal was funded and executed and led to the results described by Alcamo *et al.* (1998), Leemans *et al.* (1998) and Leemans and Kreileman (1999).

Generally the Board was impressed by the overall scientific quality and the innovative aspects of IMAGE 2. They especially mentioned feedbacks and linkages, and the geographic explicitness and regional detail of the model. However, the board suggested that more efforts should be directed towards 'adequate reality checks' by verification and validation by setting up a validation experiment to simulate the developments of the last 100 years. The board further emphasised that enhancing scientific credibility could be addressed by expanding collaboration with other research institutes and programmes and by frequent publishing in the peer-reviewed literature. Especially in the Terrestrial Environment System (TES) and the Energy Industry System (EIS) the economic flows should be modelled more adequately. The linkage to WorldScan model for the world economy should become more pronounced. Further forestry, biomass energy (and since Kyoto, also C-sequestration in forests) should be added as part of the land-use model, but also in an economically feasible way.

A continued involvement in the different assessments of the Intergovernmental Panel on Climate Change (IPCC) was advocated by the Board because it would strengthen the visibility and acceptance of IMAGE 2. The Board further concluded that informing international climate-change negotiating bodies with IMAGE-2 results would be most appropriate. The Conference of Parties (CoP) of FCCC would be the most appropriate target. A clear entry into the negotiation and policy-making process (i.e. the Kyoto Protocol), must be elaborated upon. Here again, the IMAGE-2 team should focus on the role of the biosphere and the interactions in the climate system. It was argued that a comprehensive set of baseline and mitigation scenarios should be developed. Finally, it was suggested that the IMAGE-2 team could well explore certain global-scale risk questions raised by Article 2. Besides the explicit model recommendations, the Boards also advised to develop a more appropriate interface to communicate model results to the user community.

Tables 1-4 summarises the recommendations and suggestions made during the last meeting of the Advisory Board and list the products and achievements that resulted from it. From this table it can be concluded that over the last few years most of them are implemented, documented and published in the scientific literature. Major exceptions, however, are the development of cost curves characterising different land-use and energy mitigation options, the incorporation of a good agricultural economy model, linking the N-cycle with the C-cycle, comprehensive validation exercises and a complete uncertainty analysis of IMAGE 2.

The cost curves were not accomplished because they strongly rely on bottom-up inventories of regional and sectoral mitigation options. The development of such curves for a global model is time consuming and tedious and their reliability on the longer-term is questionable. The only integrated model that includes such database is AIM (Morita *et al.*, 1993) but in this model the database is only implemented for Southeast Asia. The advantage of including these cost curves is that costs-benefit analysis could be performed for different mitigation scenarios and that optimal mitigation scenarios can be defined. In IMAGE 2 such analysis is limited because also the damages of climate change in monetary terms are not specified. Several activities, however, are planned (Appendix G). For example, the AIRCLIM project develops these curves for Europe. The EU-funded project GECS aims to develop such cost curves for land-use mitigation options. Also in the research plan of the COOL project, such analysis is anticipated, if necessary with other models such as WorldScan. The second poor implementation of the recommendations was the development of a comprehensive agricultural model, which deals with trade, land preferences for all land uses. To develop such economic framework only limited funding was available. A contract was granted to the Free University in Amsterdam (Mr. R. Gerlach, supervised by Prof. Verbruggen). In close collaboration with the IMAGE-2 team, Mr. Gerlach developed a simple scheme that focussed on the land-use intensity of food products (in m^2/Kcal), as a proxy for prices. Utility curves of diets were developed for all regions. This model resulted in diets that shift towards less affluent products, when land becomes limited and that shift towards more affluent products when income per capita rises. The parameters of the utility functions were calibrated by the economic optimisation package GAMS (Huiberts, 1997). The other land uses (forestry, biomass energy crops and C-sequestration crops) and (possible changes in) trade patterns are not included and are dealt with in the heuristic land-use systems (Alcamo *et al.*, 1998). This creates an imbalance in the current model.

Table 1 Policy recommendation made by the second meeting of the Advisory Board and the resulting achievements by the IMAGE-2 team

Tasks	*Achievement*	*Publication*	*Comments*
Develop integrated reference and policy scenarios	Several baseline, stabilisation, emissions reduction and other (including the SRES) Scenarios are developed	Alcamo *et al.*, 1996 Posch *et al.*, 1996 Alcamo *et al.*, 1998 Leemans, 1999	
Identify consequences of different policies	Stabilisation, emissions reduction and other Scenarios are developed	Alcamo *et al.*, 1995 Alcamo and Kreileman, 1995 Swart *et al.*, 1998	
Analyses the consequences of Article 2	Development of global climate-change indicators and their evaluation in scenario studies	Alcamo *et al.*, 1995 Alcamo and Kreileman, 1995 Swart *et al.*, 1998 Leemans and Hootsmans, 1998	
Add biofuel as a mitigation option	Biomass crops were added and the IPCC biomass scenarios evaluated	Leemans *et al.*, 1996	
Analyse the importance of economic and other flexible instruments	Link with WorldScan enhanced and several analyses conducted. Also some possibilities in TIMER.	Bollen *et al.*, 1998 Bollen *et al.*, 1998 Berk *et al.*, 1999	Additional activities for EMF
Develop cost curves for CO_2 and non-CO_2 mitigation options	NOT EFFECTIVELY DONE because lack of bottom-up expertise. TIMER uses CO_2 costs curves.		Done in the AIRCLIM project by TNO
Organise Dialogue Workshops between scientist and policy makers	Initially in the IMAGE-2 project, now part of the COOL project	van Daalen *et al.*, 1998 van Daalen *et al.*, 1998	Very well received by participants

Table 2 Recommendations to enhance model credibility and validation made by the second meeting of the Advisory Board and the resulting achievements by the IMAGE-2 team

Tasks	*Achievement*	*Publication*	*Comments*
Develop a 100-year historic database for validation of IMAGE-2 results	The Hyde database results from this suggestion. Only partly used for validation exercises.	Klein Goldewijk and Battjes, 1995 Klein Goldewijk and Battjes, 1997 Leemans and Klein Goldewijk, 1997	Hyde is now also used for IGBP and WCRP
Develop a comprehensive uncertainty analysis	In collaboration with Dr. van der Sluijs, this project will be executed in the period 2000-2001		
Further regionalisation	Impact indicators have been developed for different regions a new 17-region version will be developed for IMAGE 2.2	Swart *et al.*, 1998 Leemans and Hootsmans, 1998	
Develop regional centres of IMAGE 2	IMAGE 2.1 is installed at EuroPRIME institutes, China and the US (EPA & Pennsylvania State Univ.)		Collaborations not effective due to limited resources

Table 3 Model recommendation made by the second meeting of the Advisory Board and the resulting achievements by the IMAGE-2 team

Tasks	*Achievement*	*Publication*	*Comments*
Energy Industry System			
Add fuel supply constraints and trade in EIS	TIMER has been developed and will replace the current models in EIS	de Vries and van den Wijngaart, 1998	Final implementation delayed until 2000
Add CFC substitutes and improve/update emission factors	Done	Alcamo *et al.*, 1998	Data updated again for IMAGE 2.2
Terrestrial Environment System			
Add supply/demand & trade model for forestry and food in TES	A simple agricultural economy model and trade has been developed	Huiberts, 1997 Alcamo *et al.*, 1998	No working version yet in IMAGE 2.2
Add a global wood-product cycle	The C-budget of wood products has been added	Alcamo *et al.*, 1998 Kreileman and Alcamo, 1998	
Improve estimation of crop yields by adding land degradation and irrigation	WaterGap is developed in collaboration met Univ. Kassel and a land degradation model together with ISRIC	Conway *et al.*, 1996	Other publications under development
Improve land-cover change model	Heuristic land-cover rules improved	Alcamo *et al.*, 1998	
Add cost curves for non-CO_2 land-use emissions	NOT DONE due to lack of expertise		Partly addressed by GECS
Improve land-use emission factors	Updated figures and improved simulation of relevant processes	Alcamo *et al.*, 1998	
Improve impact indicators	A workshop was organised to discuss and further develop such indicators. The proposed indicators are realised.	Leemans, 1998 Leemans and Hootsmans, 1998 Leemans, 1999	
Add carbon sequestration and biofuels	Done in collaboration with EuroPRIME	Kreileman and Alcamo, 1998	Will be improved in future versions
Evaluate joint implementation approaches with respect to land use	Will be done in the GECS project		
Add a nitrogen cycle	A preliminary N-reduction factor was added, but full-scale N-cycle was not because of lack of additional funding		Will be part of 'Land-climate interactions' and A-TEAM project
Atmosphere Ocean System			
Improve the credibility of radiative forcing calculations	Done	Alcamo *et al.*, 1998	
Include the effects of sulphur and sulphate aerosols	Done	Alcamo *et al.*, 1998	
Evaluate if the replacement of the current 2-d climate model with ECBilt is feasible	Radiation scheme for ECBilt developed and strategy for implementation of ECBilt in IMAGE 2.3 comes into view	Schaeffer *et al.*	Further development in NRP-project land-climate interactions

Table 4 Other recommendations made by the second meeting of the Advisory Board and the resulting achievements by the IMAGE-2 team

Tasks	Achievement	Publication	Comments
Publish special issues on IMAGE 2.1 and applications	Accomplished	Alcamo *et al.*, 1996 Alcamo *et al.*, 1998	
Develop a comprehensive User Support System	The PSIR structure was used to visualise IMAGE-2 data and results. The USS was linked to a extensive online documentation	Leemans *et al.*, 1998	3000 CD-ROMs distributed
Develop 'screening versions of the IMAGE-2 model	Several simplified tools (SLA, ISS, and FAIR) are developed on basis of IMAGE-2 results. These tool address specific policy issues.	Alcamo *et al.*, 1996 Alcamo *et al.*, 1997 Berk and Janssen, 1997 Swart *et al.*, 1998 Berk and Janssen, 1998 Berk and den Elzen, 1998 Berk *et al.*, 1999	Maintenance of these derived tools need a large share of IMAGE-2 capacity
Provide input to the global-change research programmes	IMAGE-2 team is active in several core projects of IGBP, IHDP and WCRP	Walker *et al.*, 1997 Cramer *et al.*, 1999	

The third major neglect of the recommendations was improving the linkage between the nitrogen and C-cycle. This was important because in many regions of the world, climate is not the limiting factor but nitrogen and other nutrients. Including nitrogen, as is nowadays routinely done in dedicated global biogeochemical models, such as Century (Schimel *et al.*, 1996) and TEMS (McGuire *et al.*, 1997), will provide better estimates of plant growth and decomposition, and thus the global carbon fluxes. Also nitrogen plays in important role in determining the processes that alter these fluxes dynamically. IMAGE 2 utilises nowadays a very simplistic nitrogen-availability correction factor on productivity. This factor is based on local soil characteristics. This is inadequate to simulate changes in interactions and feedbacks. A first improvement was developed for the TARGETS model (den Elzen *et al.*, 1997) but this was based on static carbon and nitrogen ratios. A research proposal to NRP by Leemans to develop a more adequate model was judged appropriate by RP-reviewers, but unfortunately not funded due to lack of NRP-recourses. The 'Land-climate interactions' and the A-TEAM project will both incorporate this topic, so that in the near future it could be addressed.

The fourth recommendation that was not completely implemented was the development of a comprehensive validation and uncertainty analysis. However, the first steps were initiated. The Advisory Board proposed that a historic database for the input variables of IMAGE 2 was developed so that the model could be started in 1880 and run towards 2000 to see if reasonable results for regional statistics and geographic patterns are obtained. Such validation exercise could enhance believe in the synopsis of IMAGE-2 simulations for the period 2000-2100. The first part was done as the Hundred Year Database for the Environment (HYDE) (Klein Goldewijk and Battjes 1997). There is currently a comprehensive historic database of IMAGE-2 variables. The land-use components have reasonable coverage and algorithms are developed to fill gaps. The energy-related variables, however, show much larger gaps partly because a large part of the energy carriers before 1940 were not included in official statistics. Over this period of interest there was a large shift from traditional towards commercial fuels. Using HYDE for validation of IMAGE 2, however, proved difficult. The database was not an independent description of the Environment. Many of the data gaps had been filled with similar logic as the algorithms in IMAGE 2. The first validation runs looked promising, but often resulted from circular argumentations, which are unsuited for a rigorous validation.

Fortunately, more independent databases for historic climate (New *et al.*, 1998), land use (Ramankutty and Foley) and population have been developed. The availability of these databases will in the near future probably lead to better possibilities for such validation exercise. Over the coming two years, many of these historic database will be checked and further developed as part of an inter-core project comparison of (regional) land-use databases within the International Geosphere Biosphere Programme (IGBP) and the International Human Dimension Programme (IHDP). The HYDE database will participate in this comparison. The historic land-cover patterns of HYDE have also been submitted to the World Climate Research Programme (WCRP) to be included in the ISCLSP CD-ROM with input datasets for climate models.

Finally, the advisory board strongly recommended that an uncertainty analysis be performed. Several components of IMAGE 2 have been analysed separately (e.g. Alcamo *et al.*, 1998) but not together. Much emphasis has been laid upon the feedbacks in the C-cycle, on the sulphur emissions and TIMER, but no overall uncertainty analysis is performed for the whole model. Such project has now been funded by NRP (Appendix G) and will be executed by Dr. Jeroen van der Sluijs (Utrecht University). We will focus on the SRES scenarios and use the NUSAP approach (van der Sluijs, 1997) to define different types of uncertainties in IMAGE 2.

Conclusions

Concluding, most of the recommendations of the second advisory board were carried out over the last years. The dialogue workshops with the IMAGE-2 team and FCCC negotiators were successful. New model developments and applications were published in many papers (see Appendix 1 of final NRP report; Leemans and Kreileman, 1999) and all members of the IMAGE-2 team lectured on many occasions in national and international fora (see Appendix 2 of final NRP report; Leemans and Kreileman, 1999). Also the IMAGE-2 scientific contributions to the international research programmes of IGBP, IHDP and WCRP, and the assessments of IPCC are significant. A summary of all IMAGE-2 applications is given in Appendix D.

This success was strongly due to the flexibility with which the structure of the modelling framework was extended (Figure 2). Initially, most applications and developments focussed on the development and applications of the core model of IMAGE 2. Over the last years, however, several derived tools are developed and applied to specific policy questions. These tools are the Safe Landing Analysis (SLA; Kreileman and Berk, 1997), the Interactive Scenarios Scanner (ISS; Berk and Janssen, 1998) and Framework to Assess International Regimes for Burden Sharing (FAIR; Berk and den Elzen, 1998; den Elzen *et al.* 1999). These last two tools use a simplified version of the IMAGE-2 atmospheric chemistry, C-cycle and climate module. This is Meta-IMAGE (den Elzen, 1998; c.f. Figure 2). The new TIMER model, the Energy-Industry Emission model and the meta-IMAGE model can be used as a stand-alone model to rapidly evaluate energy scenarios. IMAGE 2 and its modules and derived tools are now thus developed in a much more modular way, which enhances flexibility.

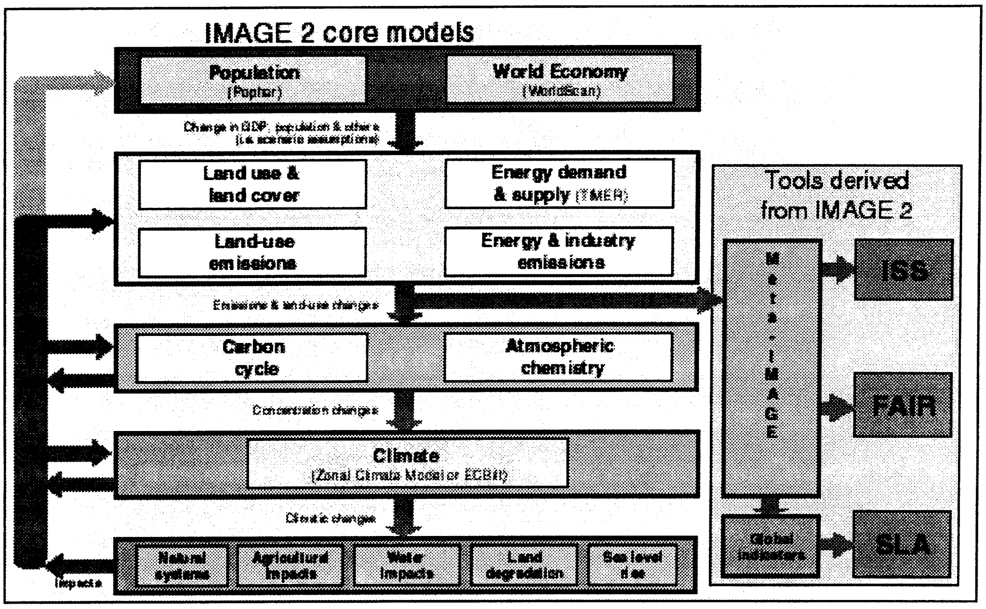

Figure 2 The structure of the IMAGE-2 core model (emissions to impacts) and the derived tools

The need of this development was foreseen by the second meeting of the Advisory Board, who suggested that a fast screening IMAGE-2 could be very useful. Although most of these tools have been developed as part of other climate-change related projects (see below), and have been very useful and effective from a policy and scientific perspective, their development and maintenance nowadays capture a substantial proportion of the resources allocated to IMAGE-2 and climate-change research at RIVM. This limits the further development of the IMAGE-2 core model

.

3. Institutional imbedding of the IMAGE-2 project

The Dutch National Institute of Public Health and the Environment (RIVM) consists of 5 divisions (1. Vaccines; 2. Public Health Research; 3. Analytical and chemical laboratories; 4. Substances and Risk; and 5. Environmental Research. c.f. Figure 3). The environmental divisions 4 and 5 have as their core tasks (1) to describe the current status and future developments in the environment on the basis of (alternative) policy solutions, and carrying out the related research, and (2) to provide policy support and government supervision in environmental research issues and calamities. These tasks thus both relate to policy development and policy implementation. Their assessments strongly focus on the quality of the environment and the impacts of changes as a function of possible socio-economic developments at the national, European and global levels.

RIVM has been active in the area of climate change research since the late 80s and the institute's internationalisation strategy intends to consolidate or strengthen the relevance of its international research work. During the last decade several integrated assessment models have been developed (e.g. IMAGE 1.0: Rotmans, 1990; IMAGE 2.0: Alcamo, 1994; TARGETS: Rotmans and de Vries, 1997) and applied to national and international policy fora, such as FCCC-CoP, IPCC and UNEP and the international scientific programmes of IGBP, WCRP and IHDP. The institute is very eager to develop the appropriate tools and methods to assess the robustness of these integrated assessments at different levels.

Climate-change related projects at RIVM

Four large projects of the institute currently address global climate-change issues. These are:

1. the IMAGE-2 project, which is led by Rik Leemans (MNV), Bert de Vries (MNV) and Eric Kreileman (CIM);
2. the 'Climate-Change Policy Support', which is led by Bert Metz (MNV);
3. the EDGAR-project, which is led by Jos Olivier (LAE); and
4. The COOL project, which is led by Dr. B. Metz (MNV) and Drs. Marcel Berk (MNV).

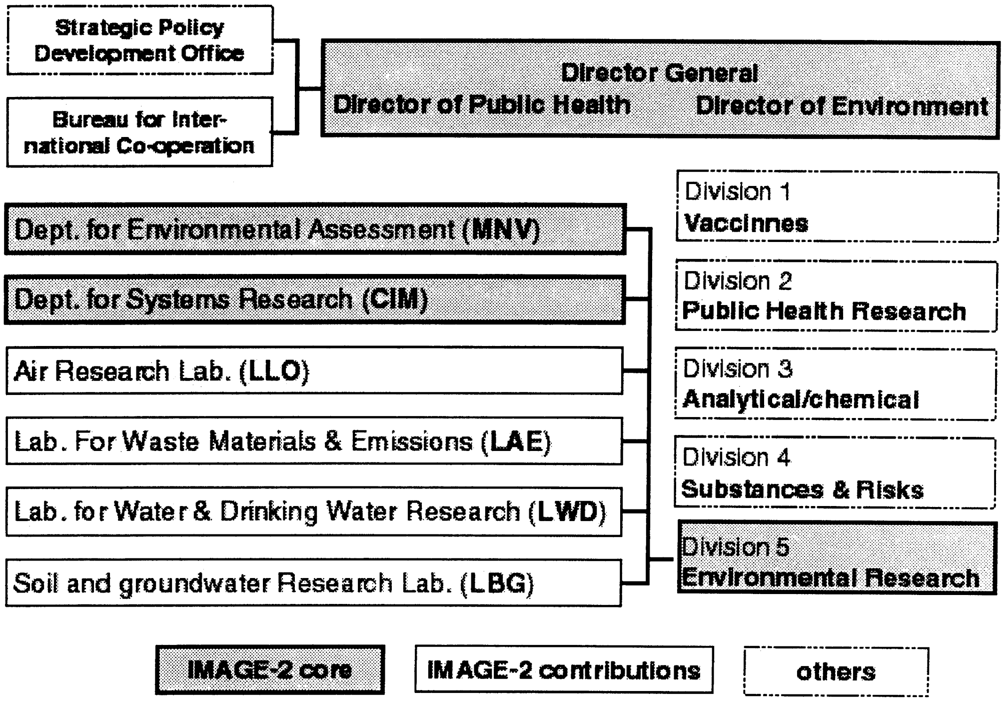

Figure 3 Organisational structure of RIVM in relation to MAGE-2 research

First, the IMAGE-2 project aims to further develop this integrated assessment model with adequate resolution to cover key processes in the earth system and to link these processes to human activities and responses. The Department of Environmental Assessment (MNV) is taking the lead in further developing and applying IMAGE 2 (i.e. IMAGE-PLUS project, which is led by Rik Leemans & Bert de Vries), while the Department of Environmental Systems Research (CIM) is responsible for the final integration of individual modules, model maintenance, support and version management of IMAGE 2 (i.e. IMAGE maintenance & support project, which is led by Eric Kreileman).

Second, the project 'Climate-Change Policy Support', which is led by Bert Metz (MNV), focuses on applying results from IMAGE 2 and the derived scanners and other relevant insights and expertise to address timely climate change issues at national and European scales. This project directly addresses the specific climate-change policy questions from Dutch Parliament and Government and focuses on the effectiveness of different instruments, such as joint implementation (JI), emission trading, the Clean Development Mechanism (CDM) and C-sequestration by forestry and land use. It further focuses on FCCC related questions such as impacts of climate change on developing countries, link between ozone and climate change and the consequences of altered UV radiation. Both the IMAGE-2 and 'Climate-Change Policy Support' project consists of several subprojects, often funded by other agencies than VROM or RIVM. The International scanners subproject is led by Michel den Elzen and is also part of the 'Climate-Change Policy Support' project.

Third, a large emissions database, EDGAR (the EDGAR-project, which is led by Jos Olivier), is maintained and developed at the Department for Waste Materials and Emissions (LAE). EDGAR covers world-wide emissions on a sectoral, national and, where ever possible, geographically explicit, of all greenhouse gases for the period 1900-1995. LAE also prepares the Dutch national communications of greenhouse gas emissions (e.g. Olivier *et al.*, 1999).

Finally, the COOL-projects aims to explore long term options for climate protection and their implications for the medium term on the basis of a dialogue between scientist, policy makers and other stakeholders. The project consists of three subprojects: on the national (Netherlands), national, European (EU) and global (FCCC) scale (Appendix G). Although COOL is funded by NRP it is a major MNV project. The IMAGE-2 model and its derived tools are particularly relevant for the COOL global dialogue project, which is led by Marcel Berk.

IMAGE 2 is further used by several other projects, such as the development of the Dutch state-of-the environment report and the European and global environment outlooks for respectively the EU and UNEP. Jean-Paul Hettelingh (MNV) and Keimpe Wieringa (MNV) co-ordinate the European activities, while Jan Bakkes (MNV) co-ordinates the UNEP projects.

The staff for these projects consists of 20 members, who have a permanent contract with RIVM (Appendix D), (17 research staff and 3 support staff) Not all of these people work full-time, however. The total full time equivalents (FTEs) are 16.2. Additionally we have 7 temporary staff, who is hired to accomplish a certain task or to complete a PhD-thesis on an aspect of climate-change. These latter staff members are connected to a University as well.

The size of the team seems well suited to continue the development and applications of IMAGE 2. The size is comparable to other large integrated-modelling teams, such as at Batelle PNL (US), MIT (US) and NIES (Japan). However, looking at the level of scientific expertise within the IMAGE-2 group it becomes obvious that there is a high reliance on junior researchers, while senior researchers dominate the other groups. Several senior researchers (e.g. Alcamo, Rotmans, and Swart) have taken other position inside and outside

RIVM and are not replaced or replaced by junior scientists. This could in the future jeopardise the scientific quality and acceptance of the IMAGE-2 research.

Additionally, the technical support unit of IPCC's working group 3 resides in MNV and is directed by Rob Swart, while Bert Metz is the co-chair of this working group. This unit comprises of three full-time staff members but does not conduct or rely on RIVM's climate change research. Several Dutch ministries fund the TSU. Its main task is to support the development of the third Assessment report and several special reports of this Working Group.

Project planning

The institute has a 4-year planning horizon for all of its projects (i.e. the so-called MAP). Annually, these plans are adjusted to the current needs. The applied environmental research (i.e. MAP-Environment) has to be approved by the Ministry of VROM. The projects in this MAP are responsible for the production of the Dutch state-of-the-environment reports, the monitoring networks and ongoing applied research. Additionally, a strategic research plan (i.e. MAP-SOR) is prepared. MAP-SOR draws on 20% of all research resources and addresses upcoming environmental issues and its research allows the further or new developments of tools and understanding needed in the near future. The climate change projects are split over MAP-Environment and MAP SOR. The IMAGE-2 Maintenance & support, climate-change, EDGAR and COOL projects are part of MAP Environment. IMAGE-plus is part of MAP-SOR. Most externally funded activities (c.f. Appendix G) reside under the IMAGE-plus project.

The purpose of the annual planning cycles is to allocate the necessary expertise and other resources over the different projects. This set-up allows that specific expertise from a dedicated sectoral laboratory in any division (e.g. Figure 3) can be allocated flexibly to projects that require that expertise. The allotment of the resources is based upon priorities set by the requirements of the ministry of VROM and RIVM's laboratory heads and higher management. Project leaders prepare and communicate their needs, and adjusts them if not all required expertise is available.

This institutional and planning structure leads to research involvement of all Sector-5 laboratories in the climate-change related projects (c.f. Appendix G). However, the time of individual researchers is often divided over several projects. Unfortunately, due to influences uncontrollable to project leaders, such as ad-hoc priorities, expertise is therefore often not available when needed due to other priorities of laboratories or departments.

National and international collaboration

In order to enhance the research capacity and expertise needed for the development and applications of IMAGE 2 several research collaborations have been developed. This was also one of the recommendations of the second meeting of the Advisory Board. Within the Netherlands the most important collaborations are:

- **Centre for Climate Research** (CKO), in which the Dutch Royal Meteorological Institute (KNMI), the Institute for Marine and Atmospheric Research (IMAU) of Utrecht University, and RIVM collaborate on climate-climate research. Rik Leemans is a member of the Programming Board. The development of the link between ECBilt and IMAGE 2 is one of the major CKO collaborative research projects.
- RIVM closely collaborates with **the CPB Netherlands Bureau for Economic Policy Analysis** on applying WorldScan. In 1997, CPB and RIVM jointly participated in the IPCC-Energy Modelling Forum-14 workshops, dealing with a model comparison on economic impacts from reduction strategies aiming for concentration stabilisation (Bollen *et al.*, 1998). In 1998, research capacity regarding climate economics of both institutes focussed on the first and second budget period as mentioned in the Kyoto protocol. More specific, this research dealt with the topic of ceilings on the use of flexible instruments (Bollen and Gielen, 1999). And currently, a NRP funded project has started to analyse the economic impacts of long term stabilisation of greenhouse gases in the atmosphere, against the background of the newly developed IPCC scenarios. This project is lead by Johannes Bollen.
- **Centre for Climate Change and the Biosphere** (CCB), in which the Agricultural Research Institutes (DLO) and different departments of the Agricultural University of Wageningen develop a common programme for climate research. RIVM is not officially a member, but will be practically in the near future through the proposed appointment of Rik Leemans as Visiting Professor at the Agricultural University. Land and land-use related research will be the main focus of CCB and individual CCB researchers are eager to evaluate, use, and further develop the TES components of IMAGE 2. The NRP-funded

land-climate interactions project already provides a strong research link between CCB & CKO

- **Centre for Energy Research**, in which the Department of Science, Technology & Society of Utrecht University, The Dutch Energy Research Centre (ECN) and RIVM co-operate in the development of methodologies to analyses energy-scenarios and the resulting emissions and possible mitigation options. From the IMAGE-2 group Bert de Vries actively participates in this consortium. This consortium also evaluates international burden sharing methodologies by the development of analytical tools, such as the FAIR model. Marcel Berk and Michel den Elzen are principal researchers from the IMAGE-2 group, who work on this topic.

The most important international collaborations are:

- **The European partnership for Research on Integrated Modelling of the Environment** (EuroPRIME), which consists of the IMAGE-2 team at RIVM, the Wissenschaftliches Zentrum für Umweltsystemforschung of the University of Kassel (Joseph Alcamo); the Potsdam Institute for Climate Impact Research (PIK; Wolfgang Cramer), the Environmental Change Unit of Oxford University (ECU; Tom Downing) and the Centre International de Recherche sur l' Environment et le Dévelopment (CIRED; Jean-Charles Hourcade).

  The objectives of EuroPRIME are to: (1) encourage and support a unique European approach to integrated environmental modelling and assessment, (2) develop a common European modelling platform for scientific support of environmental change policies, and (3) enable the further development of integrated models of the environment, especially on the regional, continental and global scale. By sharing their effort within EuroPRIME, partners are able to develop, support and use large-scale integrated models without having to expend a large individual effort. Partner institutes contribute to EuroPRIME by devoting in-house resources to constructing new model components, preparing model inputs and databases, producing and analysing model scenarios, organising meetings, and related activities. EuroPRIME initially focuses its co-operative efforts on furthering the development and applications of the IMAGE-2 model because it is in an advanced state of development, and can make significant immediate contributions to global change policy and science.

The development of the hydrology module of IMAGE 2 is currently one of the main activities of EuroPRIME. Other activities involve the land-climate interactions and the C-sequestration modules of IMAGE 2. Also the projects A-team and GECS (Appendix G) will be components of EuroPRIME research.

- IMAGE 2 has been installed at several **regional centres**, such as the Climate Impact Centre of the State Environmental Agency in Beijing, China, the Environmental Research Laboratory of the U.S. Environmental Protection Agency and the Center of Integrated Regional Assessment of Pennsylvania State University. Others possible centres are being evaluated (e.g. in Costa-Rica, India and/or Bangladesh) but due to lack of adequate capacity, no decisions have been made yet. The purpose of these centres is to apply IMAGE 2 for regional assessments, to obtain improved data coverage for defining the initial condition of IMAGE 2, and to develop improved scenario assumptions for these regions.

Finally, the IMAGE-2 team participates in several international networks that aim at improving the use of models and understanding the relevant processes:

- The **Energy Modelling Forum** (EMF) is a Stanford-University based initiative, led by John Weyant, to bring together many modellers t discuss each others results and compares model results. The annual meeting in Snowmass (CO) focus on diverse impact studies. Other activities include specific analysis of flexible instruments, energy scenarios, etc. Both IMAGE and WorldScan results have been presented and discussed at these meetings.
- The **European International Forum on Integrated Assessment** (EIFIA) is funded by the EU and studies and promotes the use of integrated assessment (IA) approaches. Specific topics, (e.g. participatory IA, IA models and uncertainty analysis) are presented and discussed at their workshops. The IMAGE-2 team plays an active role in this forum.
- The **Global Modelling Forum** (GMF) of UN-commission on Sustainable Development was initiated in 1997 to evaluate the use of IA models and to promote their use in developing countries. The activities initiated involved global and regional scenario comparison. Currently GMF tries to analyses the environmental consequences of development using an array of models. The Image-2 team has submitted their scenario results.

4. Current activities and future developments

During the autumn of 1999 the leaders of RIVM's climate-change projects (Eric Kreileman, Rik Leemans, Bert Metz, and Marcel Berk) and related projects (Jan Bakkes and Jean-Paul Hettelingh) gathered to discuss and develop a common view on desirable future activities within the projects. The main purpose of this discussion was to identify common needs and required tools and to develop a comprehensive strategy for future model development and applications. Co-ordination between the different projects was an additional objective of these meetings. The meeting already resulted in a better harmonisation between the projects and the discussions will therefore continue on a regular basis also in the future.

Identification of important topics that are already addressed

Past and current applications were analysed (Appendix F). It is clear that IMAGE is applied for many different assessment and policy discussions ranging from national, multi-national, regional to global (Figure 4). The Image-2 team has frequently contributed to IPCC assessment (e.g. Alcamo *et al.*, 1995; Leemans *et al.*, 1996; Harvey *et al.*, 1997) and will be contributing even to the third assessment. The Dialogue workshops directly addressed the needs of FCCC negotiators. IMAGE 2 contributed to IGBP and IHDP research. Finally, frequent sessions with Dutch and European policy makers were organised to address policy development and evaluation.

An inventory and analysis of recently started activities and desirable activities was made (Appendix F & G). From these projects it becomes apparent that all our activities cover four main topics (enhance the dialogue; improving economics; adding C-sequestration; improving mitigation scenarios; and improve impact assessment) and some smaller specialised topics (e.g. infectious diseases; interactions among environmental issues; improving emission factors related to IMAGE core, and broadening participation in COOL).

First, the need to make the science-policy dialogue more efficient by enhancing the communications and develop dedicated tools to analyse timely policy questions is strongly recognised. The COOL project and 'Climate-Change Policy Support' projects strongly emphasise this aspect but it is also relevant for the national and international environment outlooks that needs transparent and informative indicators for climate change.

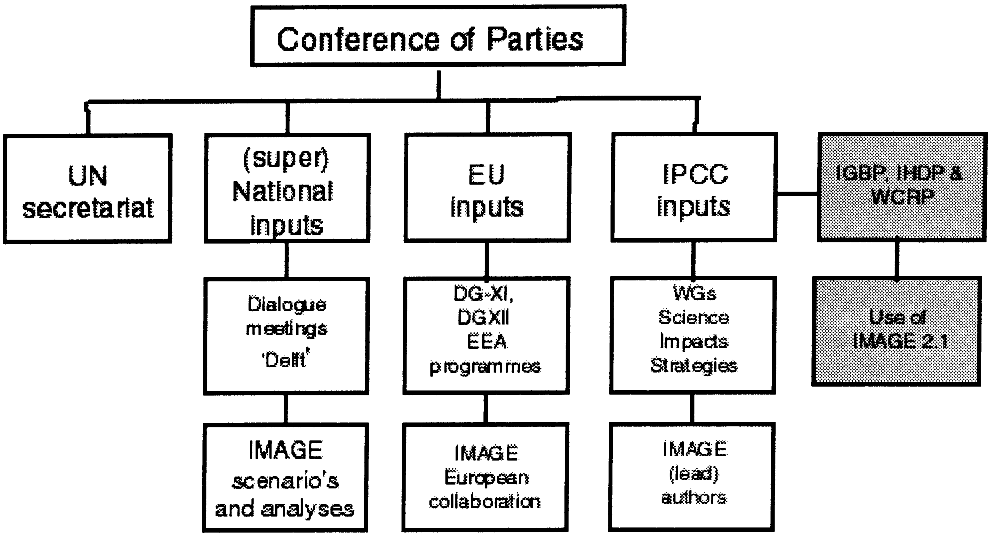

Figure 4 The applications of IMAGE 2 to directly and indirectly support FCCC

Second, several projects emphasise the improvement and use of economic tools, such as the link with the world economic model WorldScan. This is a direct consequence of repeated request during the Dialogue workshops (van Daalen *et al.*, 1998). Johannes Bollen in close collaboration with researchers from CPB develops and communicates new and innovative applications to evaluate flexible instruments and other issues relevant to the Kyoto protocol. The WorldScan User Support System (WUSS) is instrumental to communicate these results. In a requested but not yet submitted proposal to the EU, an improved analysis of the importance of changes in technology will be conducted. The experience with the current WorldScan related projects show that these are a complementary addition to the capabilities of the TIMER model, which replaces EIS in IMAGE 2.2.

Third, there was a strong emphasis on developing adequate ways to analyse the potential of C-sequestration as specified in the Kyoto protocol. Both the 'Climate-Change Policy Support' and COOL projects urge further developments in this field. The externally funded projects in IMAGE development (GECS, LBA Carbon, Land & climate and A-team) should provide such capability.

Fourth, the development of an improved and more regionalised impact assessment capability for developed and developing countries have led to several activities. It is recognised that the current climate-change scenario algorithm in IMAGE 2 is limited. It focuses on pattern scaling of GCM results on the basis of mean annual temperature change (c.f. Appendix G in

Alcamo *et al.*, 1998), this leads to gradual changes in long-term means and could give misleading views on impacts. The state-of-the-art assessments no use more elaborate transient scenarios and try to incorporate climate variability (e.g. Mearns *et al.*, 1997). Incorporating inter-annual variability and changes therein in transient climate-change scenarios will increase the realism of impact assessments. The ECBilt project provides the opportunity. ECBilt will be effectively linked to IMAGE 2 in the land & climate project. A-team will provide improved ecosystem models that can cope with such scenarios. The activities in the IMAGE-development project on hydrology and land degradation, and the infectious-diseases project also contribute to improved enhanced impact assessments.

Identification of important topics that should be addressed in the near future

The group then discussed desired development on basis of foreseen applications. These applications were primarily focussed around the FCCC negotiations and IPCC assessments and scenarios developments. Although other aspects could become important on the longer-term (e.g. improved impact assessment), we were convinced that most relevant analyses were covered by the current projects and planned activities over the next few years. The relevant policy questions identified during the latest COOL workshops strongly focussed on scenario development, the potential of flexible mechanisms, burden sharing, C-sequestration, impacts on developing and develop countries (regionalisation), impacts of technology transfer and ancillary benefits (c.f. Appendix F). The scientific instruments/analysis to address these are macro-economic models, simple climate models/scanners, energy/technology models, improved transient climate-change scenarios, and a better regionalisation of assessments. The developments of most of these instruments/analyses are addressed in ongoing or planned projects.

Table 5 Desired improvements and new developments for IMAGE 2.3 and beyond (based on a detailed analysis presented in Appendix F)

Task	**Period (years)**	**Addressed (potentially) by**	**Main target audience**
Continued policy-science dialogue	Always	Climate change and COOL	MB/MV and FCCC
Keep IMAGE and its tool up-to-date	Always	IMAGE maintenance	MB/MV and FCCC
Improved link with world-economy model (WorldScan)	0-2	Climate change and WUSS	MB/MV, FCCC, IPCC, UNEP-GEO, World Bank and UN-CSD
Improved treatment of technological dynamics	0-2	WUSS, IMAGE development	MB/MV, FCCC, IPCC, UNEP-GEO, World Bank and UN-CSD
Improvements of simple models and scanners	0-2	Climate change and COOL	MB/MV and FCCC
Improved trade model	2-4	IMAGE development	MB/MV, FCCC, IPCC, UNEP-GEO, FAO, World Bank and UN-CSD
Improved potential to develop mitigation scenarios	0-4	IMAGE development, & Climate Change	MB/V, FCCC
Improved evaluation of C-sequestration potential	0-2	COOL Land & climate, GECS, LBAcarbon, A-TEAM	FCCC, IPCC and FAO
Improved land-use economy model	2-6		MB/MV, FCCC, IPCC, UNEP-GEO, FAO, World Bank and UN-CSD
Enhanced link with emission databases (e.g. EDGAR)	0-2	EDGAR, IMAGE maintenance & development	MB/MV, FCCC and IPCC
Improvements of the present mitigation scenarios	0-2	Climate change, COOL and AIRCLIM	MB/MV, FCCC and IPCC
Regional European policy applications	0-4	Climate change and AIRCLIM	MB/MV, EU, IPCC, UNEP-GEO
Developing countries policy applications	0-4	IMAGE development and climate change	MB/MV, FCCC, IPCC, UNEP-GEO, FAO, World Bank and UN-CSD
Links to other environmental stresses (e.g. acidification)	0-4	AIRCLIM	MB/MV, FCCC, IPCC, UNEP-GEO and UN-CSD
Improved indicators for biodiversity	0-2	IMAGE development	IPCC, UNEP-GEO and FAO
Development of an integrated hydrology model	0-2	IMAGE development	UNEP-GEO, FAO, World Bank and UN-CSD
Development of an integrated land degradation model	0-2	IMAGE development	MB/MV, FCCC, IPCC, UNEP-GEO, FAO, World Bank and UN-CSD
Development of true transient scenarios with inter-annual variability	2-4	ECBilt and Land & climate	MB/MV, FCCC, IPCC, UNEP-GEO, FAO, World Bank and UN-CSD
Improved simulation of biogeochemical cycles (C & N)	2-6	A-TEAM and Land & climate	FCCC, IPCC, UNEP-GEO, and FAO
Improved modelling of agricultural systems and ecosystems	4-6	A-TEAM and Land & climate	IPCC, UNEP-GEO, FAO, World Bank and UN-CSD
Improvement of regional impact assessments	0-6	IMAGE development, climate change and infectious diseases	MB/MV, FCCC, IPCC, UNEP-GEO, FAO, World Bank and UN-CSD
Links to local environmental issues	0-2		MB/MV, FCCC, IPCC and UNEP-GEO

For a better integration of these (regional) issues, also a land-use economic model and water-use model are desired. A water model (WaterGap, Alcamo *et al.*, 1997) is developed within EuroPRIME. No fundamental activities are planned for a land-use economic model[3].

Jan Bakkes stressed that there were several other potential target organisations, who all are developing global assessment reports. We already have applied IMAGE-2 results for the Dutch state-of-the-environment and outlook reports (e.g. RIVM, 1999), European assessments (e.g. European Environment Agency, 1998) and for UNEP's ongoing Global Environment Outlook (GEO) programme (e.g. United Nations Environment Programme, 1997). In these report the integration of climate and other environmental issues is essential. Important is the development of comprehensive scenarios in all these studies (Appendix F).

Additionally the UN Commission on Sustainable Development has approached RIVM to participate in their Trend-II report, FAO in their 'Agriculture towards 2015 & 2030' report, and, finally, the World Bank on their 'World Development Report'. These organisations are all interested in RIVM's expertise in scenario development and in determining/assessing the environmental consequences of different developments. It is important to note that all of these other target audiences expect global scenario studies by approximately the end of 2000.

Strategy for further development and application of IMAGE 2

Although the IMAGE-team at RIVM is responsible for the final integration of the model and the FCCC, IPCC, European and national applications, we recognised that the further development and IMAGE cannot be done solely at RIVM. This has major consequences for the future of the project. Below some elements are listed which are part of the future research strategy of the continuation of the IMAGE-2 model and its applications.

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[3] Although WorldScan incorporates the agriculture and forestry sector as part of the world economic system, this has not been intensively to improve the land-use simulations in IMAGE. In developing the SRES scenarios, only some of the trade patterns were adjusted according to the WorldScan simulations. The biggest miss-match between WorldScan and the agricultural economy model in IMAGE2 is that WorldScan totally depends on monetary units to determine flows between sectors and regions, wile IMAGE approximates this by land-use intensity (c.f. Alcamo *et al.*, 1998; Huiberts, 1997).

- The model should be capable to address important emerging issues in climate-change and other environmentally policies. The IMAGE-2 team should develop an intuitive feel for what becomes important within a few years. This is a major challenge. An efficient retrieval of new insights from the scientific literature and participation in cutting-edge workshops and international assessments, like those by IPCC and the international research programmes, is essential to maintain such capability.
- The IMAGE-2 team should continue with the dialogue sessions to monitor changes in policy relevance of past, current and future issues. This will facilitate the timeliness of applications and creates a short and direct connection between the generators and user of model results and insights.
- The development of a scientifically state-of-the-art integrated assessment models that address these emerging policy issues, probably requires additional detail and modules. This increases the complexity of the model and require more computing resources. Moreover, much effort will be needed for keeping the model transparent by the development of user interfaces and proper documentation.
- It is inevitable that RIVM cannot alone provide broad enough expertise to cover all necessary disciplines in enough detail. It is therefore necessary to develop strong and lasting scientific collaborations with selected scientific partners to further develop (components) of IMAGE 2. The existing networks of CKO, CCB, CPB and EuroPRIME should be strengthened. IMAGE could become a policy-relevant, integrating framework of distinct research within these networks. RIVM will, however, remain responsible for the final integration of IMAGE, for version management, and for the communication among partners. Strengthening these collaboration also means trying to improve access national and international funding sources to adequately finance these collaborations;
- It is inevitable that RIVM cannot alone provide broad enough expertise to cover all necessary regions in enough detail. Regional networks of selected collaborating centres are necessary. It could well be possible to link to the current network of UNEP's collaborating centres that are involved in GEO and to improve existing (e.g. USA and China) and develop new regional centres. Several institutes already have contacted us, but up-to-now adequate funding and personnel resources have limited such regional extension;

- Innovative dedicated but flexible derived tools for policy analysis should be developed whenever necessary and possible. However, the development and maintenance of these tools require resources and could compete with the development and application of the core IMAGE-2 model. Additional resources are thus required for the adequate further development, maintenance and use of these tools.
- The derived tools if these remain relevant for ongoing policy studies, should be updated to include most recent databases and insights. However, the maintenance of individual tools must be discontinued when they become marginally policy relevant;
- The timely contributions to IPCC and other global and regional assessments must be continued;
- Frequent publication of innovative IMAGE-2 and derived results in the peer-reviewed scientific literature is of utmost importance for the acceptance of IMAGE-2 results and applications.

5. Summaries of the presentations

Overview of the IMAGE-2 projects

Presentation by Rik Leemans

The history of the IMAGE-2 project will be illustrated by using past and current applications from the IMAGE books (Alcamo, 1994; Alcamo *et al.*, 1998) and the CD-ROM (Leemans *et al.*, 1998) and others (Appendix D). The overview will show that the IMAGE-2 project over the last years has not only been following the major recommendations of the second meeting of the Advisory Board but also adapted flexibly to timely and upcoming policy issues by applying IMAGE, communicating important findings and developing dedicated tools, such as the Safe Landing Approach.

The overview will then summarise the material on project structure and institutional imbedding presented in the earlier Chapters of this report. This will highlight some of the current constraints of the IMAGE-2 project, which must be dealt with. The success of simultaneously developing a state-of-the-art detailed dynamic simulation model, deriving flexible tools, linkages to other models, and applying these models to assessments with different regional or sectoral scopes, has lead to some fragmentation of the focus of the IMAGE-2 team. This could results in the near future in difficulties in maintaining all models.

The above synopsis leads to specific questions to the Advisory Board (c.f. Chapter 6), which will be presented and explained in detail.

The IMAGE realisation of the SRES scenarios

Presentation by Bert de Vries, Johannes Bollen, Michel den Elzen, Eric Kreileman & Lex Bouwman

The new IPCC scenarios for the Special Report on Emission Scenarios (SRES) are based on a different scenario approach than earlier ones. This time story-lines with four largely different worldviews are used to distinguish between possible scenarios. These worldviews differ with respect to globalisation (A1 & B1) & regionalisation (A2 & B2) characteristics and favour either a most economically (A1 & A2) or environmental-equity (B1 & B2) optimised perspective. Different modelling groups have elaborated on the story lines of these scenarios and used their models to quantify them further. From the resulting scenarios, specific marker scenarios, which will be the reference for each story line, were selected for each story line. The IMAGE-2 team has elaborated upon the B1 marker scenario, which will be described in more detail.

The B1 scenario specifies a greenhouse-gas (GHG) emissions path for a world that chooses collectively and effectively to pursue service-oriented economic prosperity while taking into account equity and environmental concerns, but without any explicit policies directed at mitigating climate change.

In the scenario, after peaking around 2050 at 2.2 times the 1990 level of primary energy use, a number of factors lead to a primary energy use rate at the end of the next century that is only 40% higher than the 1990 rate. Among these factors are a stabilising (and after 2050 declining) population, convergence in economic productivity, dematerialization and technology transfer, and high-tech innovations in energy use and supply. Land-use related emissions show a similar trend. Total CO_2 emissions peak at 12.8 GtC/yr around 2040, after which they start falling off. Other GHGs emissions show a similar trend as CO_2 . The resulting CO_2-equivalent concentration continues to rise to about 600 ppmv in 2100. Present understanding of climate change impacts suggest that even in this world of high-tech innovations in resource use in combination with effective global governance and concern about equity and environment issues, climate policy is needed if mankind is to avoid dangerous interference with the climate system.

The presentation highlights the storyline, describes how it has been implemented in the WorldScan and IMAGE-2 models. The main results will de discussed.

An Economic Assessment by the WorldScan model

Presentation by Johannes Bollen, Ton Manders[4], & Hans Timmer[4]

WorldScan is a global Applied General Equilibrium model. The application of the integrated WorldScan - IMAGE framework distinguishes four important steps. In the first step WorldScan is used to simulate global scenarios for the economy for the 1995-2100 period. These scenarios are translated to inputs to be used by the IMAGE model, i.e. the TIMER model of the EIS system and the Agricultural Demand module of the TES system. Based on economic pathways, TIMER generates energy pathways. In the second step, these energy pathways are in turn used as input to the WorldScan model to redefine the WorldScan energy profiles generated in the first step.

In the third step, we simulate the macro-economic impacts and effects on energy markets of imposing global constraints of CO_2 emissions. It is assumed that in the medium term the Annex-1 region (OECD regions and Economies in Transition) will undertake the abatement effort and comply with the Kyoto protocol. For the longer term all non-Annex-1 countries gradually, based on a welfare trigger, will join the Annex-1 group of countries. The ultimate aim of the global CO_2 constraint is to meet the requirement of stabilising concentrations at 550 ppmv.

Generally, climate policy makers are also involved in developing the stabilisation scenarios, and in this way we can improve the policy relevance of these scenarios. One of the problems for researchers is how to communicate assumptions and results of the stabilisation scenarios. As a result of the fourth step, we present a dedicated tool, called the WorldScan-User Support System (WUSS), which has been developed to visualise assumptions and results of the WorldScan model runs. WUSS is also designed in such a way that it will facilitate the pre-selection of scenarios, which have been analysed with both IMAGE and WorldScan, and therefore assists in the process of integrated assessment. WUSS therefor helps to improve the communication of integrated assessments to other scientists and policy makers.

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We will present how a specific burden sharing rule yields different regional target profiles, if the global policy either calls for an early action or a delayed response. It is shown that by applying a system of tradable permits to achieve a global constraint, new partners can be attracted to join the abatement coalition. But it is also shown that some countries within the abatement coalition might be against entry of any new partners. Also we will illustrate that the evolution of permit markets will be less stable in a situation of early action than with a delayed response.

Energy-Economy Model and TIMER in EIS

Presentation by Detlef van Vuuren & Bert de Vries

At the moment, we are working on replacing the original EIS model of IMAGE 2.1 with the more detailed TIMER 2.2 model. An important reason for this development is that over the past years identifying ways to mitigate greenhouse gas emissions has become even more important than before for policy development. Energy consumption and industrial activities are by far the largest emission source. The major objectives of TIMER 2.2 are:

- to analyse the long-term dynamics of the energy system, and in particular changes in energy demand and the transition to non-fossil fuels within an integrated modelling framework; and
- to generate greenhouse gas emission scenarios that are used in other submodels of IMAGE 2.2.

The most important differences of EIS and TIMER are (1) the former is mainly an energy demand model, while the latter includes the full energy supply/demand circle, and (2) the latter can be used as a stand-alone model to quickly scan consequences of different assumptions and scenarios, which can, after selection, be calculated within the total IMAGE framework.

The TIMER model consists of five submodels: Energy Demand, Electric Power Generation, and the supply models for Solid Fuels, Liquid Fuels and Gaseous Fuels and is directly linked with the Emissions model. All submodels are currently being implemented for 17 global regions, which can interact in the form of fuel trade. In its formulation, the TIMER model combines bottom-up engineering information and information on specific rules and mechanisms about investment behaviour and technology to simulate the structural dynamics of the energy system.

In short, the Energy Demand model simulates energy demand for five different energy carriers (solid, liquid, gaseous, traditional biomass and electricity) and five economic sectors on the basis of a variety of factors including economic output and structure, technological progress, energy prices and assumptions with regard to lifestyles and energy and environmental policies. The Electric Power Generation model analyses how electricity demand will be met by hydropower, non-thermal electricity (solar, wind, geothermal or nuclear) and thermal electricity (based on fuels). The three supply models analyse how energy demand is met by the production of fossil fuels or by alternative biomass-based fuels and calculate corresponding energy prices (taking into account depletion and technology trends). In the model, demand can not only be met by domestic production, but also by global fuel trade among all regions.

In the past year, we have focussed on extending the existing TIMER 0.4 model to 17 world regions and improving the models performance in the 1970-1995 period on the basis of available energy data. For this purpose, we have built a data set of energy and economic information at the level of 17 global regions – which has been extracted from major data sources and as far as possible checked for major inconsistencies (in particular the energy demand data). Obviously, the move to 17 global regions did require considerable effort as the new IMAGE 2.2 regions are mostly data poor.

At the same time, TIMER (based on its implementation for 13 regions) has been applied in the generation of the new integrated IPCC scenarios. The team has in particular played an important role in the generation of the B1 scenario, for which the model in view of its detailed description of energy supply and demand seemed to be very fit. In addition, also the A1 scenario was simulated. These applications gave considerable information on the most important uncertainties within the model. These include:

- development of energy intensity as a result of structural change processes (dematerialization, growth of service and information sectors etc);
- future development of conservation-cost curves;
- the outward ends of long-term supply curves for natural gas and oil (non-conventional supplies);

- the rate of technological development with regard to non-fossil based fuels;
- interactions between the regions (trade, technology transfer).

In the coming years, we hope to further develop the TIMER model with regard to the following aspects:

- To perform a sensitivity and uncertainty analysis of the TIMER model to better understand its bounds and stability;
- To increase the potential of the model to support policy-making by 1) including more potential policy measures (Combined Heat and Power, carbon storage), 2) to improve the formulation of potential and costs of energy conservation, 3) to implement the potential for flexible instruments and 4) to explore effects of technology transfer;
- To explore links between TIMER and economic modelling (WorldScan);
- To increase the formulation of potential of and implementation barriers for renewable energy sources. This will be done in co-operation with Utrecht University and is already funded by RIVM;
- To improve formulation of energy demand on the basis of more physical indicators, which will allow us to better indicate the potential for energy conservation, compare different regions and to provide a bridge function between bottom-up engineering type information and the top-down knowledge from economic modelling;
- To co-operate more closely with partners in different regions – in particular with regard to model application.

Energy-Industry Emissions model in EIS

Presentation by Michel den Elzen & Jos Olivier

The objective of the Energy-Industry Emission model is to calculate the regional emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), and sulphur oxides (SO_2) stemming from energy production and energy use, and from industrial production for each IMAGE 2 region. In addition the model also simulates the emissions of the halocarbons, i.e. CFCs, HCFCs, HFCs etc. The model consists of two submodels: energy-emission- and industry-emission module, calculating the energy- and the industrial related emissions of the greenhouse gases and other gases, respectively. The Energy-Industry Emission model replaces the original energy-industry emission model of the EIS model of IMAGE 2.1. The methodology used is similar as in the original version, but the major differences are:

- the emission factors for the different energy sectors and carriers for the various greenhouse gases are updated (mostly based on aggregated data from EDGAR 2.0);
- the spatial scale of the model is now extended to the 17 IMAGE 2.2 regions[5];
- the inclusion of the three groups of greenhouse gases, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6);
- the inclusion of the latest IPCC SRES scenarios.

The Energy Emissions Module

The objective of the Energy Emissions module is to calculate the regional emissions of CO_2, CH_4, N_2O, NO_x, CO, NMVOC, and SO_2 stemming from energy use and industrial production. More specifically, the main inputs of the module are the energy end-use consumption, energy consumption by electric power generation and energy production as simulated by the TIMER model. The module itself multiplies these energy flows with emission to compute the energy-related greenhouse gas emissions. The following nine energy sectors are considered:

(i)–(v) five energy end-use sectors, i.e. industry, transport, residential (households), services (commercial and public) and others (agriculture and others);

(vi) energy consumption by electric power generation;

(vii) other energy transformation,

(viii) fossil fuel production (coal production, flaring of gas associated with oil production, gas transmission, etc.);

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[5] The IMAGE 2.2 regions consist of Canada, USA, Central America, Latin America, North Africa, West Africa, East Africa, South Africa, OECD-Europe, Eastern Europe, CIS, Middle East, India + South Asia, China + centrally planned Asia, West Asia, Oceania, and Japan;

(ix) marine bunkers (international shipping).

The five energy carriers distinguished are the four types of fossil fuels, i.e. solid (coal and coal products), Heavy Liquid Fuel (HLF) (diesel, residual fuel oil and crude oil), Light Liquid Fuels (LLF) (LPG and gasoline), gas (natural gas and gasworks gas); and modern biofuels (such as ethanol).). Compared to the IMAGE 2.1, the following new elements have been added:

1. The distinction of liquid fuel into HLF and LLF;
2. The explicit inclusion of the following energy sectors;
3. Emissions from marine bunkers (notably for CO_2 and SO_2);
4. CO_2 emissions from gas flaring associated with oil production; and
5. emissions from feedstock use of energy carriers. Because of its non-energy character, the use of energy carriers as chemical feedstock is treated as a non-fuel source of CO_2 in the Industrial Emissions module.

Since we use highly aggregated sectors and energy carriers in the TIMER model, we must also use specific aggregated emissions factors. For the IMAGE 2.2 version the values of all the emissions factors have all been adapted. They are now based on aggregated data from EDGAR 2.0 (Olivier *et al.*, 1996; Olivier *et al.*,1999), except for SO_2 in industrialised regions where emission factors have been calibrated against other published emission estimates. The EDGAR 2.0 emission factors are in line with the values for CO_2 used by Boden *et al.* (1994) and for other compounds with defaults emission factors recommended by the UNEP *et al.* (1995). In fact the latter are to a large extent global aggregates of regionally aggregated emission factors from EDGAR 2.0. In simulating future emission trends, the emission factors maybe change. In the development of IPCC SRES scenarios this was most relevant for the CH_4 emissions related to fossil fuel production, CO- VOC- and N_2O-emissions from national transport sources, and NO_x- and SO_2 emissions from electric power generation and the energy end use sectors (de Vries *et al.*,1999).

Industrial Production and Industrial Emissions Module

The Industrial Production and Emissions module are used to compute emissions of greenhouse gases or their precursors that are not directly associated with energy use. The model is roughly similar to its version used in the IMAGE 2.1 model, except for the inclusion of the three groups of greenhouse gases, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). These gases were added in the Kyoto Protocol together with CO_2, CH_4 and N_2O. The emissions of these compounds are set exogeneously, based on the IPCC SRES emissions scenarios developed by Fenhann (2000). The same holds for the emissions of the halocarbons regulated in the Montreal Protocol, i.e. the CFCs, HCFCs, halons, carbon tetra chloride and methyl chloroform.

Other minor changes are the exclusion of industrial emissions sources of CH_4, adaptations of some of the emissions factors to improve agreement between the simulated emissions and the data for global and regional 1990 emissions, aggregation towards the 17 IMAGE 2.2 regions and the inclusion of the CO_2 emissions from feedstocks. The emission factors for CO_2 related to non-energy use of energy carriers as chemical feedstock are aggregated factors from EDGAR 3.0, based on IPCC recommended default factors and default fractions of carbon stored (IPCC, 1996).

For the IPCC SRES scenarios the cement production over the period 1990 till 2100 is indexed to population growth. The level of other industrial activities is indexed to the fossil energy use in the industry sector as simulated within the TIMER model.

Testing of the Energy Emissions Calculations

As testing phase we have used the Energy Emissions submodel to compute energy-related emissions of greenhouse gases. IEA statistics for the period 1970/1971-1995 (IEA, 1998) were used. The Industrial Emissions model computes non-fuel emissions related to industrial processes, including CO_2 from energy carriers used as chemical feedstock. It was found that the resulting simulated regional CO_2 emissions for the period 1970-1990 are similar to the CDIAC data (Boden *et al.,* 1994). The simulated regional SO_2 emissions for the period 1970 to 1990 are comparable Smith *et al.* (1999). For the energy- and industry-related emissions of other greenhouse gases and compounds there is no regional historical data available (except Europe and North America).

Future Research

In co-operation with the University of Kassel and TNO-MEP, the Energy-Industry emission module will be extended with methodologies for emission reduction costs and potentials for emissions of the substances NO_x and SO_2 and greenhouse gases. In first instance, the focus will be on end-of-pipe emission reduction technologies and the associated curves, especially to mitigate the emissions of NO_x and SO_2. These options will be important to identify joint strategies to control regional air pollution and climate change. Also more generic measures such as speed limits for high way traffic and building codes (volume and intensity developments), as well as present policies and autonomous developments will be included in the model to improve the different scenarios. This will lead to developments of emission factor values over time as a result of the emission reduction options.

The industry model is planned to be extended with the halocarbon emission model of Kroeze (1996) which includes a scenario model for the emissions of PFCs, SF_6 and HFCs. These developments together with a linkage with the meta-IMAGE model, enable us to perform multi-gas assessment analyses using the Energy-industry emission model.

The Agricultural Economy Model (AEM)

Presentation by Eric Kreileman, Bart Strengers & Lex Bouwman

In IMAGE 2.1, the AEM is part of the Terrestrial Environmental System (TES) and computes the demands for food and feed crops and timber. Food and feed demands are derived from demands for 7 vegetable and 5 animal food products. Here, the focus will be on the module that computes the demand for vegetable and animal food products. The demand for timber and the translation of animal food products into feed, will be covered in another presentation. The output of the AEM is part of the input to the Land-cover Model (LCM), in which it is determined how land use and land cover will change in order to meet the demands from the AEM and the demands for bio-fuels and fuel wood from the Energy/Industry System (EIS).

The primary objective of the AEM is to supply information to the LCM in order to compute land-use and land-cover changes and the related emissions of greenhouse gasses, i.e. primarily CO_2 emissions due to deforestation and methane from livestock. Although results of model runs allow to make some general statements on food-security, a detailed simulation of global food demand and supply is not an objective of the AEM (or TES).

In IMAGE 2.0, historical consumption patterns of agricultural food products were extrapolated into the future by using semi-logarithmic functions with GDP per capita as the driving force. The consumption of all products was scaled down if overall consumption exceeds a threshold. This sometimes led to unrealistic shares of food products. During the last Advisory Board Meeting it was discussed to improve the AEM by adopting a 'simple equilibrium relation between supply and demand'. This resulted in IMAGE 2.1.

Model description and behaviour

In the AEM, food products are associated with so-called *intensities*, which indicate the amount of land needed to supply 1 Kcal/day. Because prices do not exist in the AEM, intensities are considered to be a proxy for prices. Next, there are *preference levels*, which are defined as the demands that would exist in the absence of any limits concerning for example land and income. Multiplying preference levels and intensities result in an amount of agricultural land per capita that would be needed to produce the preferred diet. This amount is called the *maximum budget.* The 'hart' of the food-related part of the AEM is a 'hill-shaped' utility function, which returns the utility-value for a given demanded diet. The maximum value is achieved at the point where the demands are equal to the preference levels. The overall shape and steepness of the utility function is determined by the preference levels and by a set of *weighing constants*. Their values indicate the eagerness or importance to the consumer to consume food products at the preferred levels. The basic idea of the AEM is to optimise the utility function for each region, given a so-called *actual* (or *total) budget* (in m^2/cap), which is equal to a fraction of the maximum budget. If income, average potential production and/or technology increase, this fraction increases also.

It is interesting to see what happens, if any of the intensities (or 'prices') decline while other factors remain equal. First of all, the maximum budget will decrease. The above mentioned fraction will increase because a decline in intensities, which is the same as an increase of yields, is, in IMAGE 2.1, always caused by an improvement of the average potential productivity and/or an improvement in agricultural technology. Therefore, in relative terms, the actual budget will converge towards the maximum budget although in absolute terms it can either go up or down. In general, the new optimal value of the utility function will be higher, confirming the general behaviour that lower intensities (or 'prices') of one of the products result in a higher utility for the consumer given a certain income.

Trade between regions is determined by *self-sufficiency Ratios* that exogeneously determine net food trade between the world regions. The approach boils down to exogenously assigning agricultural land in one region to produce food products for another, which reveals itself in the values of the intensities. For example, the intensity value for rice in Canada is equal to the weighted average of the rice intensities from importing regions.

Up to here it was assumed implicitly that the actual budget, as computed by the AEM, is always consistent with the actual availability of land in the LCM. However, in some cases it turns out the actual budget cannot be met by the LCM. When it occurs, the actual budget is reduced and the optimal diet is recomputed according to this lower budget.

Problems in the IMAGE 2.1 version

The 13 regional utility functions are shaped by a set of 353 parameters (preference, weighing constants and elasticities). Historical FAO-data on intakes, incomes, and intensities from the period 1970-1990 were used in a separate optimisation-module to determine their values.

Unfortunately, it turned out the data was too capricious to generate a solution. To solve this problem, preference levels were made time-dependent, which comes close to the introduction of intake-scenarios. In general, it is not difficult to understand why the optimisation is problematic when looking at the underlying historical data. The AEM is based on the assumption that there is a relationship at the regional level between intensities and intake levels. However, an analysis for the period 1970-1995 shows that clear relationships cannot be found for most food products, especially at the regional level.

Another problem is related to the fact that the general behaviour as described above does not always apply. There are examples in which decreasing intensities result in a lower optimal utility value. The problem even gets worse if one realises that in the current implementation the optimisation has resulted in parameter-values that eliminate the dependence of the actual budget on changes in potential productivity and technology. In other words, it has become a function of income only.

As indicated above intensities are used as a proxy for scarcity and therefore as a proxy for price. The idea is that if larger amounts of land are needed to produce 1 Kcal of a certain food product, then it will probably be more expensive because it implies an inefficient way of producing these products. However, in some regions such as South America, cattle grazes on large areas while capital and labour inputs are very low and therefore prices are too. But in terms of intensities, i.e. the amount of land needed to produce 1 Kcal of cattle meat, these products are very expensive (up too 1000 times more expensive than crop-products). This problem was 'solved' by setting an upper limit to the amount of grassland that can be assigned to cattle. In general, it can be stated intensities alone cannot serve as a proxy for price.

A decrease in one of the intensities result in a decrease of the maximum budget because less agricultural land is needed to produce the preferred diet. Consequently, the actual budget (in m^2/cap) also decreases by the same percentage. However, from the previous time-step it is known that, given a stable population size, a larger actual budget is available because the demands in that time-step were met. Therefore, there is no reason to lower the actual budget, except in case of population growth which, however, is not a variable in the AEM.

Towards a new version in IMAGE 2.2.

To solve the problems mentioned above, we are working on a new version of the AEM, in which the following major simplifications are being implemented:

1. An aggregation of food products into only 2 aggregates: 'affluent products' and 'basic products'. The set of affluent products is an aggregate of oil crops and all animal products. The basic products consist of all vegetable products excluding oil crops.
2. Make the preference levels fixed in stead of time dependent.
3. Reduction of the number of preference levels to 2 for affluent products, and 3 for basic products, based on historical data analysis.
4. Adaptation of intensities for cattle, sheep and goats by converting the grassland area into crop-area that would be needed to produce the same amount of calories.
5. Elimination of the factors 'potential productivity' and 'agricultural technology'.

Even in IMAGE 2.2, this approach result in only 51 weighing constants which should be valued with (an also simplified version of) the optimisation module. If we succeed, it can be easily checked whether the general behaviour as described above holds for this simple model.

Conclusions on AEM

A first conclusion is that the macro-economic food demand model in IMAGE 2.1 could not be parameterised using the historical data on intakes, incomes and intensities. To simulate food demand at this level of detail more dynamical aspects should be included, which would be, however, an enormous task. Therefore, in IMAGE 2.2., we are simplifying the AEM towards a level that can be handled by the current approach.

To be able to do further reaching statements on food security it would be important to focus on the following aspects, which do not only consider the AEM, but also other modules in TES:

1) Food and feed demands should be combined with other land-related non-food products (wood products, fuel wood and bio-fuels). In the current approach, their demands are simulated independently, and their land needs are given priority above food production.
2) The impact of climate variability on food production (heat and drought). Currently, only smooth changes in global average climate are considered. The integration of ECBilt in IMAGE 2.2. will be a starting point here.
3) Trade, which is mainly exogenously now, should be more dynamic, although it might be a better approach to analyse a number of trade-scenarios in case food security becomes a problem in one or several regions.
4) Irrigation and land-degradation are not included, but are essential to food production.

Existing models (or the institutes that implemented them) could be helpful in developing the above extensions. For example, IMPACT made by IFPRI, PoleStar made by SEI, the Basic Link model from IIASA or the FARM model from USDA.

Crop and livestock production and agricultural residue management in IMAGE 2

The IMAGE 2.1 method used to describe crop production was not changed in IMAGE 2.2. For livestock production a number of weaknesses were identified in the approach followed in IMAGE 2.1:

- The only types of feedstuffs considered were grass and crops, while the use of other feedstuffs such as crop residues were not accounted for.
- A change in the mix of feedstuffs as a result of a shift in the livestock production mix is not reflected by the fixed ratio crops : total feed.
- Management of crop residues was not properly accounted for.

We have modified the calculations of IMAGE 2.1 in a number of ways. The changes are related to feed requirements and the distribution over the various types of feed used. Apart from roughages (grass, fodder maize and other roughages) and crops and crop by-products (concentrates) we now distinguish animal products and crop residues. The purpose was to improve estimates of the demand for crops and crop by-products, roughages, and the associated production areas, and to add the description of the management of agricultural residues (needed for IPCC emission estimates).

Total feed requirements per head for non-dairy and dairy cattle and sheep and goats are identical to IMAGE 2.1 (Alcamo *et al.*, 1998) on the basis of EPA (1994). For pig and poultry production systems the energy efficiency is based on data from literature (De Wit *et al.*, 1996; Bos and de Wit, 1996; Simpson *et al.*, 1994), systems analysis and regional data.

For the period 1970-1995 data on feed use of crops, crop by-products and animal products (mainly milk) are from FAO (1999). The estimates for the other feedstuffs were obtained from literature and by calibration. For cattle we used data from Safley *et al.* (1992) and UNEP *et al.* (1995) to roughly estimate the fraction roughages in the diet. For many regions with extensive grazing and very high fraction of roughages of 85-95% in the diet (Central America, South America, Western Africa, Eastern Africa, Southern Africa, and Oceania), and for Asian countries (South Asia, Southeast Asia), these data had to be modified slightly. The basis for regions with more intensive production systems are the estimates of van der Hoek and Bouwman (1999). For western European countries, Canada, U.S.A., North Africa and Middle East, Eastern Europe and the former U.S.S.R the fraction roughages in the diet was assumed to be 60-80%. For sheep and goats we assumed that 95-100% of the energy intake is from roughages.

We assumed that in developing countries pigs and poultry consume 50-60% crop residues and other feedstuffs, and 40-50% concentrates. In developed countries pigs and poultry consume 25-35% residues and other feedstuffs, and the complement consists of concentrates. Sheep and goats consume 0-5% crops and crop by-products. The demand for concentrates for cattle is calculated as the difference between the total consumption of concentrates given by FAO (1999) and the demand for crops + residues from pigs, poultry and sheep and goats discussed above. The remainder of the feed demand of cattle is assumed to consist of residues and other feedstuffs.

After harvesting of agricultural crops a considerable amount of residues remain, both above- and below ground. Aboveground residues have various uses, including use as fuel and feed (straw, stubbles), and part is burnt in the field; the remainder is eventually incorporated in the soil where it is decomposed.

The fraction of aboveground residues that is burnt is 15% for developed countries and 35% for developing countries for 1990 (Smil, 1999). Fuel use is taken from Hall *et al.* (1994). The way in which feed use of residues is estimated is described above. Soil incorporation, which is needed to calculate N2O emissions according to the IPCC methodology, is the complement.

The Land-Cover Model

Presentation by Eric Kreileman

Together with the agricultural economy model, the terrestrial carbon-cycle and the land-use emissions model, the land-cover models make up the Terrestrial Environment System (TES) of IMAGE 2. Driven by information from the agricultural-economy model, the land-cover models have the objective to simulate global land-use and land-cover changes. A key aspect of the models is that it combines regional drivers of land-use changes (17 world regions) with geographically explicit information for land potential (spatial grid of 0.5° latitude by 0.5° longitude). Within the land-cover models six steps can be distinguished:

1. Using databases for climate and soil and changes in climate from the climate model a number of climate indices like the length and temperature of the growing season are calculated.
2. The climate indices of the first step are used to calculate potential vegetation and
3. To calculate potential (rain-fed) productivity of crops.
4. The potential productivity of crops is reduced by taking soil limitation into account.
5. Using the results of the previous steps for the starting year (1970) and statistics from FAO, an initial land-cover database is created.

6. Changes in the demand for land as calculated within the Agricultural Economy model and changes in the potential of land as result step 4 and 5 are brought together to simulate changes in land cover.
7. The models distinguishes five types of changes:
   - Adaptation of natural vegetation
   - Treatment of unsuitable land and extensive grassland
   - Extraction of timber
   - Abandoning of agricultural land
   - Expansion of agricultural land

The result of this last step is an updated land-cover map that is feed into the terrestrial carbon cycle where changed land cover leads to CO_2 emissions due to deforestation and fuelwood burning and, together with changes in climate, to changes in Net Ecosystem Productivity (NEP). The information of these models is together with the information of the Agricultural Economy model used within the land-use emission model to estimate emissions of the greenhouse gases and ozone precursors stemming from land-use and biotic sources (excluding CO_2).

Compared to previous versions, the land-cover models in IMAGE 2.2 use changed and more recent databases for most of the data involved. Two changes that will effect the scenario studies are the breakdown of the old region Africa into four regions and the protection of bioreserves that is introduced. Shortcomings within the current models concern mainly the crop model and the dynamics of vegetation.

Modelling fluxes of greenhouse gases and carbon in TES

Presentation by Lex Bouwman & Rik Leemans

Land-use emissions

The table below is an overview of the emission calculations in IMAGE 2.2.Where no reference is given the method is identical to IMAGE 2.1 (Alcamo *et al.*, 1998). The purpose of changes was to achieve consistency with the IPCC Methodology for National Greenhouse Gas Inventories (UNEP *et al.*, 1995).

The carbon cycle model

The carbon flux between the terrestrial biosphere and the atmosphere is determined by physiological processes, such as NPP and NEP, by ecological processes, such as vegetation succession and disturbance, and by local characteristics of land use and land cover. All these processes change under influence of altering atmospheric composition, climate, land-cover and land management. Interactions and feedbacks between these components thus strongly influence the build-up of atmospheric CO_2 concentrations.

The carbon flux between the oceans and atmosphere are influenced by the physical diffusion of CO_2 into the surface water and the marine biological processes that sequester carbon. Dead organic matter sinks to the bottom, and dissolved CO_2 is transported to deep water or again to the surface through ocean currents. All these terrestrial and oceanic processes are covered in the C-cycle models of IMAGE 2. The structure and properties of these models will be summarised and some applications will be highlighted.

The terrestrial C-cycle model has been developed over time but no changes have been made to the oceanic model. Version 2.0 (Klein Goldewijk *et al.*) used annual mean multiplication factors for the feedbacks. This resolution was increased to monthly factors in version 2.1 and the parameterisation of feedbacks was refined van Minnen *et al.*, 1996). Three new elements were included.

Table 6 An overview of the emission calculations in IMAGE 2.2

Source	**Species**	**%**	**Resolution**	**Activity level/key assumptions**	**Origin**
Biomass burning (including deforestation, savanna and agricultural residue burning)	CH_4, CO, N_2O, NO_x, VOC	CH_4:10%	Grid	Deforestation: ~ C burning Savanna burning: ~C burning Agr. Residue burning: ~crop production + burning fraction (Smil, 1999)	LCM LCM LCM
Landfills	CH_4	10%	Regional	~ urban population	Scenario
Domestic sewage treatment	CH_4	7%	Regional	~population	Scenario
Wetland rice fields	CH_4	8%	Grid	~area of irrigated, rainfed and deepwater rice. Emission factor from Neue (1997)	Scenario
Natural wetlands	CH_4	30%	Grid	Constant, based on Matthews and Fung (1987)	--
Animals	CH_4	25%	Grid	~ feed intake and animal population	Scenario/ LCM
Animal waste	CH_4, N_2O	CH_4: 3% N_2O: 30%	Grid	~ number of animals	LCM
Arable land	N_2O,NO_x	N_2O: 30% NO_x: 10%	Grid	N_2O: ~ fertilizer use and residue incorporation; and crop areas. Based on (UNEP *et al.* (1995) NOx: areas of biomes; emission factors from Davidson and Kingerlee (1997)	Scenario/ LCM LCM
Indirect sources	N_2O	30%	Region	IPCC Methodology (UNEP *et al.*, 1995); includes Leaching (~N inputs) and human sewage (~population)	Scenario
Natural soils	N_2O, NO_x	N_2O: 50% of total NO_x: 30% of total	Grid	N_2O: ~ NPP, T, soil moisture, soil type, soil fertility NO_x: areas of biomes; emission factors for biomes from Davidson and Kingerlee (1997)	LCM LCM
Post-clearing effects	N_2O, NO_x	N_2O: 6%	Grid	~ forest clearing and natural N_2O/NO_x emission	LCM
Other natural sources	CH_4, CO, NO_x, SO_2	CH_4: 6% of total	World	Constant, based on IPCC scenarios; includes CH_4 from termites and methane hydrates, CO from plants and wildfires, NO_x from lightning, SO_x from natural sources	--
Aquatic sources	CH_4, CO, N_2O	CH_4: 2% N_2O: 20% of total	World	Constant, based on IPCC (CH_4, CO); N_2O Nevison *et al.* (N_2O)	--

First, the inclusion of a dynamic vegetation-response routine, which mimics vegetation migration and establishment, was developed. The main feature of this approach is a biome-specific migration rate and distance, specific establishment capability and maturation rate, after which the spread can continue. A transient Net Primary Productivity (NPP) is defined, which gradually shift between the NPP values from the original vegetation type towards the new vegetation type. The climatic and CO_2 feedback processes continue to influence NPP during such shift. The vegetation response algorithm is parameterised in such a way that both instantaneous and very slow transients can be simulated. van Minnen *et al.* (2000) present the consequences of different migration responses and conclude that the dynamics of these spatial processes influence the build-up of atmospheric CO_2. A limitation of the current algorithm occurs when the original vegetation should have been replaced by new vegetation type under changed climate but the new type is unable to move there. We assume that the original vegetation then continues to grow albeit with probably lower NPP due to nonoptimal climatic conditions. Large scale forest disturbance under these conditions, as simulated by Neilson *et al.* (1992), do not occur in IMAGE. C release dye to climatic stress could thus be underestimated.

Second, carbon stored in timber was accounted for in the C cycle. A short-lived and long-lived timber pool was defined, with respectively a turnover time of 10 and 100 years respectively.

Third, regrowth of forest vegetation after forest harvest or abandonment of agricultural land was considered in more detail. In these cases the NPP of the regrowth forests gradually increases following a logistic curve and the cell is classified as 'regrowth forest' in the land-cover model. The vegetation type flips towards the new type when 50% of the potential NPP is realised.

No large changes have been made in the C-cycle models in version 2.2. Only the initial NPP values are updated towards more generally accepted literature values from CDIAC. Also a renewed calibration was performed. From model comparisons it was obvious that the oceanic uptake of IMAGE was relatively low (e.g. Enting *et al.*, 1994). To follow the historic observed atmospheric increases, the uptake by the terrestrial biosphere must be larger. This was achieved by assuming a relatively high NPP value for agriculture. In IMAGE 2.2 these values are much better balanced and more realistic responses after deforestation or abandonment of agricultural land are obtained.

An addition in IMAGE 2.2 are C-sequestration crops or Kyoto forests. The potential productivity of each grid cell is evaluated for optimal tree species. If this productivity over time is larger than the growth rate of current vegetation, such cell could be eligible for additional c-sequestration. Region specific sequestration levels can be specified and those will be planted in the region. In defined the efficiency of these C-sequestration crops, the current standing biomass and it use as forests products is accounted for. The algorithm is still under development in close collaboration with J. Alcamo (University of Kassel) and will be used in the NRP-funded COOL and land-climate interaction projects.

The future but longer-term developments of the C-cycle models are manifold. The 2nd meeting of the Advisory Board already indicated that linking the C-cycle to the N-cycle should be important. A simple linkage has already been developed by den Elzen *et al.* (1997) but this approach does not include systemic interactions between the cycles as are simulated in the current state-of-the-art models (e.g. Schimel *et al.*, 1996). Al these models provide approaches to comprehensively deal with integrating global biogeochemical cycles.

When in the future, the linkage between ECBilt and IMAGE has been operationalised, many of the TES models, including the C-cycle model, should be replaced to deal with more responsive models. Such modes are currently being developed. They are nowadays known as Dynamic Global Vegetation Models (DGVMs; e.g. Goudriaan *et al.*, 1999 and Foley *et al.*, 1996). DGVMs simulate physiological, ecological and boundary layer processes and comprehensively integrated all specific temporal and spatial dimensions and processes. The simulated vegetation can respond to inter-annual variability in climate by adjusting leaf areas, simulate the effects of changes in CO_2 and climate, and comprehensively deal with succession processes. The A-TEAM project aims at further developing such model and integrating it with land use. This project, in which we collaborate, could well provide IMAGE with a state-of-the-art integrated land-cover model, that simultaneously simulated C fluxes.

Simulating changes in land degradation risks

Presentation by Gert Jan van de Born

Adding dynamic changes in land degradation was one of the Advisory Board's recommendations for further enhancement of the Land-cover model in IMAGE. The argument for the necessity to enhance the model was funded by the observation that only parameters were incorporated that cause productivity growth, whereas in many locations throughout the world soil productivity is decreasing due to land degradation. Land degradation influences properties of land and affects land-use and indirectly carbon fluxes and the emissions of greenhouse gases. In the current version land degradation is considered as an optional module in IMAGE (Alcamo *et al.,* 1998). Land degradation by water erosion is the most important and responsible for about half of all degraded area. Changes in precipitation, water-availability and land use as a result of climate change together with declining extent of natural vegetation will inevitably accelerate land degradation and affect food security. Besides these links, also the interaction between water erosion and hydrology has become a feasible topic for further examination.

Terrestrial processes are simulated in IMAGE 2 on a 0.5°x0.5° longitude and latitude grid. Each grid cell is characterised by its soil qualities, terrain, climate and land cover. The first two characteristics are assumed to remain constant during the simulations, while the latter two change. However, we realise that climate change and land use influence soil quality and thus also potential productivity. Regionally explicit information on land-use systems, management practices (including degradation measures) and spatially explicit data on climate, soil and terrain properties are combined with physical and biological processes to calculate potential production losses due to land degradation. The resulting model is wherever possible based on first-order principles and developed together with the International Soil Reference and Information centre (ISRIC).

Model description

Batjes (1996) proposes a generalised model for assessing water erosion hazard (E):

$$E = f(R, T, V)$$

with

R - Rainfall erosivity index

T - Terrain erodibility factor (considering slope and soil type)

V - Land-cover factor

This model determines the impact of water erosion and generates a *water erosion risk index* based on three main parameters: *terrain erodibility, rainfall erosivity* and *land-use pressure*. These three indicators are indexed on a scale from 0 to 1.

- *Terrain erodibility* defines the intrinsic susceptibility of a soil to rainfall erosivity and is based on soil type and landform. Rainfall erosivity depends on the intensity, amount and distribution of rainfall.
- *Rainfall intensity* figures were derived from monthly precipitation values and the number of rain days. The month with maximum rainfall intensity, i.e. precipitation divided by number of rain days, is for rainfall erosivity.
- *Land-use pressure*, as defined by agricultural use, defines pressure values. These values are dependent on crop type and soil-conservation management. It is assumed that natural vegetation covers provide optimal protection.

The latter two indices change through time and are simulated using IMAGE-2 for precipitation and land cover. The number of monthly rain days are assumed constant. Two types of water erosion risk can be distinguished from these three indices:

- *Water erosion susceptibility* or the *potential* water erosion risk. This risk is calculated by terrain erodibility and rainfall erosivity. This susceptibility index is the sum of the two indicator values, rated on an index scale of 0 to 1
- *Water erosion vulnerability* or: the *actual* water erosion risk. This is calculated by terrain erodibility, rainfall erosivity and land-use pressure. This vulnerability index is calculated by multiplication the susceptibility and the land-use indicator, and is rated on an index scale of 0 to 1.

Implementation in IMAGE 2.2

Currently, IMAGE uses *soil reduction factors* to impose the limitations of soil characteristics on potential productivity. In IMAGE 2.2 the outcome of *erosion vulnerability* according to Batjes' generalised erosion model will be used to adjust the value of soil reduction factors. This approach is well suited for carbon fluxes and emissions because land-cover change patterns only need to be determined coarsely. If applications for food security (also a component of Article 2) are required, a more detailed and process-based implementation is needed (for example, the use of a crop model or use of a library of possible practices and outcomes). In the setting of the IMAGE 2 model the land degradation module could also be elaborated by including degradation related response options (e.g. soil conservation measures, or modified land-cover rules for susceptible areas).

Water demand and supply models for IMAGE 2

Presentation by Joost Knoop & Frank Kaspar

Water plays already an important role in different parts of the IMAGE 2. All crop and vegetation models depend on the determination of available soil moisture. This is calculated on basis of a simple hydrological bucket model for each grid cell (Leemans and van den Born, 1994). Horizontal water flows in the soil and over the surface are currently neglected in the terrestrial environment system. Further in the AOS climate model, water flow determines riverine input into the ocean circulation system and evapotranspiration determines the water, heat and carbon fluxes from the earth system back into the atmospheric system. All these applications use water as a mean, important for the integrated modelling but not as a goal in it self.

The implementations limited the applications for UNEP's GEO because modelling only the vertical flows limited that food-security and sustainable development applications. The GEO report lists water as one of, if not the, most threatened resources in especially the arid and semi-arid and in many densely populated regions in the world. In the future the stress on water resources will increase due to population growth, increased consumption and in some regions due to climatic change. Though climatic changes are not likely to be the most important factor in the increasing pressure on the water system, analysis of (changes in) future water stress ask for an integrative approach and IMAGE provides much of the necessary requirements in a comprehensive way.

A separate water impact module to assess global water stress will be briefly presented, with emphasis on the scale of the assessment in relation to the geographic scales of relevant IMAGE variables. The IMAGE terrestrial grid (0.5 degrees longitude and latitude) is chosen as the basic geographic scale of assessment since it matched fairly well with the scale of supply systems. Yet IMAGE output on the driving forces for water demand are on the regional scale (e.g. population growth, urbanisation). The occurrence of large differences of water demand within any IMAGE region demands for a more detailed resolution. We have developed such detailed models on basis of population density databases (c.f. Leemans and Kreileman, 1999), a global water routing scheme (Renssen and Knoop, 1999) and hydrological processes. Applications of this water-stress assessment model are foreseen within the frameworks of other RIVM projects. To add water stress to the IMAGE-output list (impacts) is a suggestion to be discussed.

For the final integration of a comprehensive water model in IMAGE, we would like to discuss to what extent common hydrological features can be generalised, what is the most appropriate resolution, and which other components that use evaporative schemes in IMAGE should be harmonised/linked with this water model.

Atmospheric chemistry modelling in AOS

Presentation by Frank de Leeuw & Michel den Elzen

Within the Atmosphere-Ocean System (AOS) a separate sub-module is included to evaluate the formation and losses of the non-CO_2 greenhouse gases in the atmosphere. Emphasis is on the description of atmospheric chemistry of OH and tropospheric ozone, which is a greenhouse gas by itself. The input to the atmospheric composition model consists of emissions of GHG and ozone-precursors (nitrogen oxides, CO and Volatile Organic Compounds); outputs are GHG concentrations.

The model can be characterized as a globally averaged box model and it includes key photochemical processes such as the production of OH from ozone and H_2O and the formation of ozone during the oxidization process of CO or CH_4. The changes in concentrations over time are described by simplified mass-balance relations; for OH an equilibrium concentrations is assumed. The parameterization of these relations has been based on 1- or 2-dimensional global models. Note that CO_2 and sulfate aerosols are not included in the module. CO2 is inert in the atmosphere and has no chemical interaction with the other trace gases. The formation of sulfate-aerosol from oxidation of SO_2 is described by linear emission-concentrations relations derived from a 2-dimensional global model.

Recently the results of the chemical composition module have been compared with the results of the MOGUNTIA model, a 3-dimensional global tropospheric model including full atmospheric chemistry. From the intercomparison it was learned that:

- Natural VOC emissions are implicitly treated in AOS. Under the assumption that the contribution to VOC emissions from natural sources (e.g. forest) is constant in time, their impact on atmospheric chemistry can easily be included in the parameterization. Now this type of emissions will be estimated in the Terrestrial-Environment System, a more explicit treatment in AOS will be needed.
- The sensitivity of concentrations on changes in NO_x emissions needs further attention. The current parameterizations is acceptable for situations with actual or increasing emissions but for scenarios with a decreasing trend in emissions the parameterization must be improved to account for the strong non-linear dependence of OH and ozone concentrations on NO_x emissions.

- The time constant for feedbacks in the system OH-CH_4-CO-O_3 is too large. Under conditions with constant emissions, the time needed after a sudden perturbation in emissions to reach a new stationary situation is extremely long.

Future developments will on the short-term focus on an improved description of the atmospheric chemistry on NO_x emissions. In the current version, constant globally averaged parameters are used to relate the changes in OH concentration on changes in NO_x emissions. This sensitivity coefficient is, however, depended on the emission level. From polluted (urban) areas to clean marine regions it even changes sign. Retaining the basis structure of AOS, a more regionalised approach to evaluate the NO_x sensitivity might repair this shortcoming.

On the long-term a more fundamental improvement will be the introduction of a 3D tropospheric model. Such a model imposes high demands on (computer) resources and it is important to guard a proper balance between demands and importance of the various sub-systems within IMAGE. Several options are open for discussion:

- Introduction of a stripped "poor-mans" version where the stripping is realized either by a low spatial resolution of by a simplified chemistry, or
- Adding an atmospheric chemical module to ECBilt.

Climate in AOS and linkage to ECBilt

Presentation by Theo Opsteegh & Michiel Schaeffer

From IMAGE 2.0 towards IMAGE 2.1

The current climate module of IMAGE 2 simulates a zonal mean climate change. The aim of the module is to 'translate' atmospheric concentration of greenhouse gases and sulphate aerosols to climate response. The latter is given in terms of trends in annual and zonal mean surface air temperature and precipitation.

A new development of IMAGE 2.1 (Alcamo *et al.*, 1998) as compared to version 2.0 is the distinction of 2 or 3 land masses per zonal band, to better take into account the geographical pattern of sulphate aerosol forcing. A second new feature is the calculation of sea level rise. Global mean sea level rise results from spatial averaging the thermal oceanic expansion plus contributions from changes in mass balance of the major glaciers and the Greenland and Antarctic ice sheets.

As in IMAGE 2.0, longitude-latitude patterns and changes in seasonal cycle are obtained by a simple downscaling procedure using GCM patterns of change. These patterns are overlaid on a present-day climate database. This procedure is analogous to that developed and used by, for example, Santer *et al.* (1990) and Schlesinger *et al.* (1997). Using output of different GCMs generally results in critical differences of local impacts, in less crucial differences on continental scale impacts and only small differences on global impacts.

The pattern-scaling approach was appropriate in the early nineties when the module was developed, systemic insights were less well developed and computer resources were limited. Nowadays this approach is less suited. Also, the 2-dimensional climate model puts strong limitations on both research and policy applications. The model has less degrees of freedom than GCMs, does not represent dynamic changes in ocean circulation and is incapable of representing coupled atmosphere-ocean variability on a decadal time scale. Last, but certainly not least, a more process based, 3-dimensional model would be better suited for a dynamic link with the terrestrial biosphere. This allows for further studying climate-biosphere feedbacks, as well as interactions between climate and anthropogenic land-use change within the IMAGE-2 project.

Characteristics of the ECBilt 3-d climate model

At KNMI, a 3-dimensional atmosphere-ocean-cryosphere model of intermediate complexity is being developed (Opsteegh *et al.*, 1998). The objective of ECBilt is to efficiently describe coupled atmosphere-ocean variability on a decadal time scale for mechanistic climate variability and predictability studies.

The atmospheric part of ECBilt is a T21 global three level model. Two versions are under development, one with quasi-geostrophic dynamics, while another (ECBilt-PE) resolves the full primitive equations for atmospheric motion. Both versions make use of the same package of simple parameterisations for the diabatic processes (e.g. Schaeffer *et al.*, 1998). In the quasi-geostrophic version, ageostrophic terms in the vorticity and thermodynamic equations are diagnosed and included as a time and spatially varying forcing. This results in a qualitatively correct Hadley circulation and a drastic improvement in the strength and position of the jet stream and the transient eddy activity. The atmospheric model is realistic in the sense that it contains the minimum amount of physics that is necessary to simulate the planetary and synoptic circulations in the atmosphere as well as its variability on various time scales, but only for the extra-tropics in the quasi-geostrophic version. For incorporation into IMAGE, ECBilt will be coupled to the GFDL MOM ocean GCM.

The atmospheric component of ECBilt is especially suitable to be coupled to the slower components of the climate system like the oceans, the cryosphere and the biosphere. The efficiency of ECBilt makes it possible to perform many long-term simulations within a reasonable period. This means that the model can be used for various purposes, which are at present beyond the scope of state-of-the-art climate models:

- It can be used to study climate variability and climate change associated with the slower components of the earth ecosystem. Simulations of climate changes and variations on time-scales ranging from decades to many thousands of years are possible.
- Long-term simulations can be done in ensemble mode, so that signals can be separated from the internally generated noise and statistical robustness of the results can be ensured.
- Simulations can be performed for idealised conditions in which potentially important physical processes can be turned off and on (see for an example Selten *et al.*, 1999). This is a very powerful technique in order to be able to explain observed phenomena in climate models by establishing the underlying chain of cause and effect relationships. In simulations of state-of-the-art coupled GCMs an unambiguous explanation of the results is usually not possible, because the results of these simulations can only statistically be analysed.
- ECBilt is efficient enough to be incorporated in present day integrated assessment models like the IMAGE model. Its main contribution to these models is that it provides additional information on regional changes in climate variability for climate change scenarios. The efficiency of ECBilt in IMAGE is crucial to its applicability in this context.

Linking ECBilt and IMAGE

In the first, off-line, experiments, ECBilt will be forced with scenarios of combined and separated forcings of greenhouse gas and sulphate aerosol concentrations, as well as land-use changes generated by IMAGE 2. Preliminary results give suggestions for improvement of

ECBilt, for example regarding the planetary boundary layer and atmosphere-land surface interactions.

As the integration of ECBilt in IMAGE draws nearer, it becomes clear that a powerful modelling tool will emerge. The inclusion of ECBilt in IMAGE, however, raises interesting questions on exactly which experiments are conducted with the coupled system. There are two basic questions to be answered from both a scientific and policy point of view: *What* should be the deliverables (output) of ECBilt and *why* are we interested in them?

On the more technical side, including the issue of decadal variability in IMAGE/ECBilt requires a different way of conducting model experiments. Should the impact modules be driven by diagnosed variability indicators of ECBilt? Should the fully coupled IMAGE/ECBilt model be run in ensemble mode, for diagnosis of variability which includes the influence of non-linear interactions?

Finally, total calculation time of a new IMAGE version, including ECBilt, will increase, even with expected increases of UNIX workstation computer power. This means that for certain research and policy questions, it becomes more important to again invest in developing simpler, 'educational' of 'conceptual' modelling tools, designed to explore more specialised questions. A number of such tools have already been developed in the IMAGE-2 project and others will follow, drawing from results of the central IMAGE model.

The Framework of International Scanners

Presentation by Michel den Elzen and Marcel Berk

A special group of tools derived from the IMAGE models are the so-called 'scanners', or decision support tools, summarised in the Framework of International Scanners. These flexible, transparent and interactive scanners are specially meant to support policy makers in the development of long-term climate policy options, strategies and measures at the global level (FCCC), and to facilitate a dialogue between scientists and policy makers within the climate change issue. The framework now consists of the following scanners: FAIR (Framework to Asses International Regimes for burden Sharing), ISS (Interactive Scenario Scanner), SLA (Safe Landing Analysis), and the meta-IMAGE model, which forms the core climate model of the framework.

Meta-IMAGE 2.1

The meta-IMAGE 2.1 model is a simple integrated climate assessment model that on a global scale adequately reproduces the IMAGE 2.1 projections of the global climate indicators, i.e. the concentrations of greenhouse gases, the global mean temperature increase and sea level rise (den Elzen, 1998). This so-called meta-model itself is an adapted version of the biogeochemical cycles model CYCLES (den Elzen *et al.*, 1997) with a short run-time. Meta-IMAGE 2.1 is specially meant for emissions scenario analyses and in this way used by TIMER, WorldScan and the scanners. The model consists of an integration of simple box models, namely; a global carbon cycle model, an atmospheric chemistry model, and an energy balance climate model. The model describes the chain of causality for climate change on a global scale, from emissions of greenhouse gases to the changes in temperature and sea level.

In order to evaluate the Brazilian proposal, which is one of the emission reduction protocols proposed to the UN-FCCC, (den Elzen *et al.*, 1999) meta-IMAGE 2.1 has been extended by a sub-module which calculates a region's/country's attribution of the main indicators of global climate change. The aggregation was done by linking attribution of concentrations, radiative forcing and temperature increase to the origin of emissions, using as input the regional anthropogenic emissions of the major greenhouse gases regulated in the Kyoto Protocol (i.e. CO_2, CH_4, N_2O). The module includes the historical regional anthropogenic emissions of the data sets: ORNL-CDIAC, IIASA and EDGAR-HYDE.

To assess the impact of various climate models and model uncertainties on the countries/region's attribution of global mean temperature increase, as well as on the global temperature increase itself, the meta-IMAGE 2.2 model also includes other global carbon cycle and atmospheric chemistry models, and temperature impulse response functions. The latter are based on simulation experiments with a variety of Atmosphere-Ocean General Circulation Models (AOGCMs) i.e. ECHAM, GFDL, CSIRO and HADLEY.

FAIR (Framework to Asses International Regimes for burden Sharing)

The FAIR 1.0 model allows the user to interactively evaluate the implications of different initial allocations of emission rights (permits), and thereby scan the likely consequences for global climate change and its impacts. This model is designed in such a way that many different criteria for burden sharing can be used, so as to support policy makers in evaluating options for international burden sharing. The model relates burden sharing schemes to global climate protection targets and calculates the respective regional emission permits. Three different approaches of defining burden-sharing schemes are included in the model:

- Increasing participation: Parties involved in the burden sharing gradually increase their participation according to participation rules, such as the contribution to global warming.
- Convergence: All parties participate in the burden-sharing regime with e.g. per capita emission permits converging over time.
- Triptych: is a sector approach to international burden sharing which assumes bottom-up improvements in energy-efficiency and decarbonisation targets for the internationally-oriented energy-intensive industry sector and the power generation sector as well convergence of per capita emissions in the domestic sector.

The first two modes are representatives of top-down methodologies, so from global emission ceilings to regional emission budgets, whereas the triptych approach is more bottom-up in character, although it can be combined with specific emission targets.

The Interactive Scenario Scanner (ISS)

The ISS is a computer model that assists in the interactive construction and evaluation of long-term emission scenarios using the parameters of the Kaya Identity (Kaya, 1989) to define scenarios and the main global climate indicators to scan their likely consequences for global climate change and its impacts (Berk and Janssen, 1997). This tool can be used to construct proto-scenarios, which can then be further elaborated and analysed with such sophisticated energy and climate change models as IMAGE 2. For the calculation of the climate implications of the emissions scenarios the meta-IMAGE 2.1 model is used. Recent experiences with the application of ISS indicate that it will indeed be useful in involving policy makers at an early stage of scenario development. Moreover, ISS has also been shown useful in educating policy makers on the complexity of the problem and enhancing communication between, and among, scientists and policy makers.

The Safe Landing Analysis (SLA)

The Safe Landing Analysis is an interactive decision support tool to calculate the range of short-term global greenhouse gas emissions controls compatible with long-term and intermediate climate goals: the safe emissions corridors (Alcamo *et al.*, 1996; Swart *et al.*, 1998). These corridors indicate the range of short term greenhouse gas emissions that are compatible with particular sets of specified short and long-term (2010 to 2100) climate goals (defined as limits for climate impact indicators) and maximum rates of emission reductions (as a proxy for economic and technological constraints for global emission control). The Safe Landing Analysis tool based on regression analyses uses results from the integrated climate change computer model, IMAGE 2, but could also be based on the meta-IMAGE 2.1 climate model.

6. Specific questions to be addressed by the Advisory Board

The objective of this advisory board is twofold. First, version 2.2 of IMAGE is almost ready. Some new elements (e.g. TIMER, land degradation and water) have been added and certain aspects of the model have been improved (e.g. 17 regions, AEM and climate scenarios). These are small improvements compared to the new elements and improvements in IMAGE 2.1 recommended during second meeting of the IMAGE Advisory Board (Table 1-4). Although no specific meeting of the advisory board has reviewed version 2.1, consistency and applicability has been checked by several peer reviewers during the publication of the special issue of the journal Global Environmental Change (Alcamo *et al.*, 1996), the second IMAGE book (Alcamo *et al.*) and of the final IMAGE NRP-report (Leemans and Kreileman, 1998)[6]. The Advisory Board should thus direct its review on the scientific quality of past and current research and development activities towards IMAGE 2.2.

Second, we would like to obtain advice on the specific scientific quality of the planned activities and projects and how the policy relevance and applicability of the model can be enhanced.

Advice on more detailed questions and issues are specified in the following bullets:

- What are the key scientific questions that IMAGE 2 should address (but does not already address)?
- What are the key policy questions that should be addressed?
- Should more environmental issues be incorporated (e.g. economics; health, biodiversity; food security; sustainable developments) or should the current emphasis on climate-change issues be modelled in more detail (e.g. improved atmospheric chemistry, emissions, feedbacks, etc.)?
- Should greater emphasis be put on model development or on communication of model results?

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[6] Generally, all reviewers were very positive about the model and its applications. The anonymous NRP reviewers prized the width of the model and the innovative FCCC applications and IPCCcontibutions. They stressed that the international acceptance of the model was a good indicator for scientific quality and policy relevance. However, they all recognised the uniqueness of the IMAGE-2 approach by stating that is was a pity that not more models of this kind were developed so that a thorough comparison could be conducted.

- What would be state-of-the-art tools for the forthcoming FCCC and IPCC applications (e.g. climate variability; impacts; C-sequestration; flexible instruments)?
- How can the balance between model components be maintained and improved?
- What should be the balance between IMAGE applications and development?
- What should be the balance between IMAGE-core model and derived tools?
- Should we further develop national and international scientific and regional collaborative networks?
- Who are potential developers and/or users of IMAGE 2 and its results that have not yet been contacted by the IMAGE-2 team?
- What would be feasible resource requirements and funding agencies for setting up effective scientific and regional collaborations;
- What is an adequate level of research resources and personnel for maintaining the IMAGE-2 project?

The above questions clearly specify that the IMAGE-2 team cannot do all desired activities in all detail. It is highly unlikely that the tenured staff (Appendix E) will be expanded. Major reductions are also not foreseen. However, clear priorities should define which activities will be carried out. Choices thus have to be made. We would appreciate guidance from the Advisory Board.

Appendix A. Programme of the third Meeting of the Advisory Board

Sunday 14 November	Time
Arrival in the Ernst Sillem Hoeve	
Diner	19.00 - 21.00

Monday 15 November: All participants	Time
Welcome by Prof. Klaas van Egmond (Director RIVM)	9.00 - 9.30
Background and programme of the Advisory Board by Rik Leemans	9.30 - 9.45
Introduction of participants	9.45 - 10.00
Overview of the IMAGE-2 project by Rik Leemans	10.00 - 11.00
Coffee and tea break	1100 - 11.15
The IMAGE implementation of the SRES scenarios by Bert de Vries, Johannes Bollen, Michel den Elzen, Eric Kreileman & Lex Bouwman	11.15 - 12.15
Lunch break	12.15 - 13.15
The Energy - Industry System (EIS)	
WorldScan by Johannes Bollen	13.15 - 14.00
Energy-Economy by Detlef van Vuuren & Bert de Vries	14.00 - 14.45
Energy-industry emissions by Michel den Elzen & Jos Olivier	14.45 - 15.00
General discussion on EIS	15.00 - 15.30
Tea and coffee break	15.30 - 16.00
The Terrestrial - Environment System (TES)	
The Agricultural Economy Model by Eric Kreileman, Bart Strengers & Lex Bouwman	16.00 - 17.00
Discussion by the Board on topics presented during the 1st day	17.00 - 18.00
Drinks and informal gathering	18.00 - 19.00
Diner	19.00 - 21.00

Tuesday 16 November: all participants	Time
The Terrestrial - Environment System (TES) (continued)	
The Land-cover model by Eric Kreileman	9.00 - 10.00
Terrestrial fluxes by Lex Bouwman & Rik Leemans	10.00 - 10.30
Coffee and tea break	10.30 - 10.45
The Terrestrial - Environment System (TES) (continued)	
Land degradation by Gert Jan van de Born	10.45 - 11.15
Hydrology models for IMAGE 2 by Joost Knoop & Frank Kaspar	11.15 - 12.00
General discussion on TES	12.00 - 12.30
Lunch break	12.30 - 13.30
The Atmosphere Ocean System (AOS)	
Atmospheric chemistry by Frank de Leeuw & Michel den Elzen	13.30 - 14.00
Climate by Michiel Schaeffer	14.00 - 14.45
ECBilt by Theo Opsteegh & Michiel Schaeffer	14.45 - 15.30
General discussion on AOS	15.30 - 14.45
Tea and coffee break	15.45 - 16.00
Derived products of IMAGE	16.00 - 16.45
The scanners by Michel den Elzen and Marcel Berk	
Epilogue	16.45 - 17.00
Reflections on the IMAGE presentations by Rik Leemans	
Discussion by the Board on topics presented during the 2nd day	17.00 - 18.00
Drinks and informal gathering	18.00 - 19.00
Diner	19.00 - 21.00

Wednesday 17 November (Advisory Board + IMAGE-2 project leader)	Time
Preparation of advise on the required complexity of IMAGE 2 & Tools	9.00 - 10.30
Draft review and advise on IMAGE 2.2	10.45 - 12.30
Preparation of prioritisation of Future IMAGE developments	13.30 - 15.30
Tea and coffee break	15.30 - 16.00
Presentation of the Advisory Board's conclusions by Prof. B. Tinker	16.00 - 16.45
Closure of the meeting by the Chair of RIVM's CvT	16.45 - 17.00
Reception	17.00 - 18.00
Provisional diner	19.00 - 21.00

Appendix B. Participants of the third Meeting of the Advisory Board

Invited experts

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Dr. Bert de Vries

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Appendix C. Separate information provided to the participants

- Brochure on the National Institute of Public health and the Environment
- Brochure on the Department for Environmental Assessment (MNV)
- Fact Sheet on the Department of Environmental Systems Research (CIM)
- Solomon, A., (ed.), 1994. Report from the IMAGE 2 advisory board meeting in Amsterdam, 20-22 June 1994. August 1994. NRP Report no. 00-13. National Research Programme on Global Air Pollution and Climate Change, Bilthoven, 22 pp. (*send earlier*)
- Alcamo, J., Leemans, R. and Kreileman, E., 1998. Global change scenarios of the 21st century. Results from the IMAGE 2.1 model. Pergamon & Elseviers Science, London, 296 pp. (*send earlier*)
- Leemans, R., Kreileman, E., Zuidema, G., Alcamo, J., Berk, M., van den Born, G.J., den Elzen, M., Hootsmans, R., Janssen, M., Schaeffer, M., Toet, A.M.C. and de Vries, H.J.M., 1998. The IMAGE User Support System: Global Change Scenarios from IMAGE 2.1. October 1998. RIVM Publication 4815006. National Institute of Public Health and the Environment, Bilthoven, CD-rom. (*send earlier*)
- Leemans, R. and Kreileman, E., 1999. The IMAGE-2 Model: Policy and Scientific Analysis. August 1999. RIVM Publication 481508 011. National Institute of Public Health and the Environment, Bilthoven, 126 pp.
- Brochure on the IMAGE model
- Brochure on the Safe Landing Analysis
- Brochure on the National Programme Global Air pollution and Climate Change
- Brochure on the COOL project
- Overview of the UNEP's GEO-2000 report
- Evaluation of the Brazilian proposal: Elzen, M.G.J. den, M. Berk, M. Scheaffer, J. Olivier, C. Hendriks and B. Metz (1999), 'The Brazilian proposal and other options for International Burden Sharing: an evaluation of merthodological and policy aspects using FAIR', RIVM report no 728001011, National Institute of Public Health and the Environment.

Appendix D. Applications of the IMAGE-2 model

In the past few years, IMAGE 2 has been employed for many policy-relevant scientific analysis of global environmental change issues. It has, for example, been used to:

- Estimate trends in regional and global greenhouse gas emissions as affected by development of energy and changes in land use and cover (Alcamo *et al.* 1994; de Vries *et al.* 1994; Kreileman and Bouwman 1994; Alcamo *et al.* 1995; Alcamo *et al.* 1998d);
- Examine long-term changes in global land cover, and its connection to climate change and economic development (Zuidema *et al.* 1994; Leemans and Zuidema 1995; Leemans *et al.* 1996a; Leemans 1997b; Leemans *et al.* 1998);
- Analyse the global carbon cycle (Vloedbeld and Leemans 1993; Klein Goldewijk *et al.* 1994; van Minnen *et al.* 1996; Melillo *et al.* 1996);
- Assess climate change impacts on agriculture and natural vegetation (Bouwman and Leemans 1995; Kirschbaum *et al.* 1996; Leemans *et al.* 1996c);
- Analyse the impacts of climate change on sea-level rise Alcamo *et al.* 1997c; Alcamo *et al.* 1998d);
- Relate long-term climate goals with short term emission targets (Alcamo and Kreileman 1998);
- Identify the emissions and climate impacts of achieving various levels of greenhouse gas stabilisation in the atmosphere (Enting *et al.* 1994; Krol *et al.* 1997);
- Analyse the consequences of different climate treaty proposals on short-term emission targets and long-term climate impacts (Alcamo *et al.* 1997c; Swart *et al.* 1998; Leemans and Hootsmans 1998);
- Identify the costs of reducing CO_2 emissions (Bollen *et al.* 1998b);
- Develop a global environment outlook on upcoming environmental issues (United Nations Environment Programme 1997; Bakkes *et al.* 1997);
- Examine long-term trends in global forests (Kreileman and Alcamo 1998; Brown *et al.* 1996);
- Link regional air pollution with global climate change (Posch *et al.* 1998);
- Provide data and inputs for other models and studies, for example, the modelling of regional and global water availability (Conway *et al.* 1996; Alcamo *et al.* 1997a);
- Develop climate and land-use change scenarios for biodiversity studies (Sala *et al.* 1999; Leemans 1999).
- Evaluation of the Brzailian proposal and other options of International burden sharing (den Elzen *et al.*, 1999; Berk *et al.*. 1999; Berk and den Elzen, 1998)
- Contribution to the IPCC scenarios (de Vries *et al.*, 1996)
- Contributions to the third assessment report (Scenario chapters and impact synthesis).

An important vehicle for identifying applications of the model was the so-called 'Delft Dialogue', which represented a series of meetings between global modellers and policy makers concerned with the climate negotiations (Alcamo and Kreileman 1998; van Daalen *et* *al.* 1998). Through these meetings the IMAGE-2 model was applied to issues of interest to the negotiations leading up to the Kyoto Climate Summit of December, 1997 (Alcamo *et al.* 1998b; van Daalen *et al.* 1998; Swart *et al.* 1998).

Appendix E. Personnel, collaborating experts and their expertise available for the IMAGE-2 project in 2000

Person	Department	Expertise	% involvement[1,2]					
			IMmai	IMdev	COOL	CLPS	GEO	Other
Marcel Berk	MNV	Political science		10	**60**	20	10	
Jan Bakkes	MNV	Integrated Assessment				10	**60**	20
Johannes Bollen	MNV	Economics	10	70	10	10		
Gert Jan van den Born	LAE	Soil Science		20				
Lex Bouwman	LBG	Soil Science & land-use emissions	10	50	10	20	10	
Gerard van Drecht	LWD	Hydrology	20	40			10	
Michel den Elzen	CIM	Modelling; Atmospheric processes	20	30	20	20		10
Leon Janssen	LLO	Emission modeller	5	20		10		
Joost Knoop	LWD	Hydrology	10	50			20	
Kees Klein Goldewijk	CIM	Historic data		10		10	50	
Eric Kreileman	CIM	Modelling; Model integration	**50**	20	10	10		10
Rik Leemans	MNV	Ecologists; TES, C-cycle & Impacts	20	**40**	20	10		10
Frank de Leeuw	LLO	Atmospheric chemistry	10	10		20		
Bert Metz	MNV	Policy negotiations			20	**30**		
André de Moor	MNV	Economist		20	20	40		
Jos Olivier	LAE	Emission expert				40		
Rineke Oostenrijk	CIM	User interfaces & DSS	80	10				
Bart Strengers	MNV	Modeller; TES	30	20	10	20	10	10
Bert de Vries	MNV	Energy use	10	**40**	20	10	10	10
Detlef van Vuuren	MNV	Environmental Scientist	10	20	20	20	10	
Jaap van Woerden	CIM	GIS and global data sets	20			30	30	
		Total tenured staff (person years)	**3.1**	**4.8**	**2.2**	**3.2**	**2.2**	**0.7**

Notes: 1) IMmai: maintenance IMAGE and derived tools; IMdev: IMAGE development; COOL; CCPS: Climate Change Policy Support; GEO: UNEP's GEO; 6 are all others (IPCC contributions; MB/MV).
2) Figures in bold type-phase denote project leaders

Temporary staff

Person	Department	Expertise	% involvement[2, 3]				
			IMmai	IMdev	COOL	CLPS	GEO
Henk Hilderink	MNV	Modeller & demographer		60			40
Michiel Schaeffer	MNV/KNMI	Physicist (Climatology)		80	20		
Monique Hoogwijk	MNV/UU	Energy economist		100			
Jelle van Minnen	MNV	Ecologist			100		
Vacancy GECS	MNV	Economist or modeller		100			
Vacancy uncertainty	MNV	Statistician/ or modeller	50				
Vacancy Land use	MNV	Climatologist		100			
		Total temporary staff (person years)	**0.5**	**4.4**	**1.2**	**0.0**	**0.4**

Collaborative experts

Person	Affiliation	Collaborating in:	Expertise
Theo Opsteegh	KNMI	CKO	Climatologist, GCM modeller
Pavel Kabat	WURC	CCB	Hydrologist; Land-atmosphere modeller
J. Alcamo	Univ. of Kassel, Kassel	EuroPRIME	Atmospheric scientist; Integrated Assessment modeller
Wolfgang Cramer	PIK, Potsdam	EuroPRIME	Ecologist; Global Vegetation Modeller
Tom Downing	Univ. of Oxford, Oxford	EuroPRIME	Agronomist; Agricultural Impact and Adaptation Assessments
Jean-Charles Hourcade	CIRED, Paris	EuroPRIME	Energy economist

Appendix F. Major policy questions and required IMAGE modules and further developments

Policy Questions and issues (short term & longer term)	relevance: low / high	Macro-economic instruments	Technological innovation	Climate sensitivity	Climate variability	Regionalisation	land-climate Interactions	Land-use economics	Water use
Dutch national Policy(MB/MV)		***Essential***	***essential***	***desired***	***Required***	***Essential***	***desired***	***Essential***	***Desired***
➲ Performance of international Agreements		WUSS, TIMER	TIMER	ECBILT				WUSS	
➲ Dutch contribution to environmental change abroad					ECBilt				
➲ Analysis of persistent environmental problems					IMAGE + ECBilt	IMAGE-17			
➲ Impact of EU-policies					IMAGE	IMAGE-17			
FCCC (climate change)		***Essential***	***essential***	***essential***	***essential***	***Essential***	***required***	***Essential***	***required***
➲ Potential of flexible mechanisms		WUSS, TIMER				IMAGE-17			
➲ Potential of sink enhancement		GECS, TIMER			LBA	IMAGE-17, LBA & GECS			
➲ Impacts of CC on developing countries		WUSS				IMAGE-17			
➲ Impacts of mitigation on developing countries		WUSS				IMAGE-17			
➲ Impacts of technology transfer		WUSS, TIMER				IMAGE-17			
➲ Burden sharing		FAIR							
➲ Ancillary benefits		WUSS, TIMER				IMAGE-17			
➲ Reference & mitigation scenario development		WUSS, FAIR, TIMER				IMAGE-17			
➲ Mitigation & stabilisation scenarios		WUSS, FAIR, meta-IMAGE, TIMER				IMAGE-17			
➲ Regional impacts & Article 2				ECBilt, IMAGE7, land/climate	ECBilt, IMAGE-17, Land/climate	IMAGE-17	A-TEAM, IMAGE-17, Land/climate		WaterGap
➲ Adaptation									

EU applications	*Essential*	*Essential*	*essential*	*essential*	*Essential*	*desired*	*essential*	*Required*
➲ Integration of climate & other environmental assessments	WUSS, TIMER, AIRCLIM	AIRCLIM			AIRCLIM/ EUROMV/CCE ?			
➲ Cost optimisation of climate policies	WUSS							
➲ Ancillary benefits of climate policies					IMAGE, WUSS			
➲ Development of comprehensive scenarios	WUSS, TIMER				IMAGE-17			
UNEP (Global Environment Outlook)	*Required*	*essential*	*required*	*required*	*Essential*	*desired*	*essential*	*Required*
➲ Economic and policy instruments	WUSS, TIMER				IMAGE-17			
➲ Regionalisation of impact scenarios								WaterGap
➲ Regional land and water use problems					IMAGE-17			WaterGap
➲ Urban air-pollution								
➲ Biodiversity scenarios					IMAGE-17			
OECD (Sustainable Development Programme)	*Essential*	*essential*	*required*	*required*	*Essential*	*desired*	*Required*	*Desired*
➲ Energy scenarios	TIMER, WUSS				WUSS, TIMER			
➲ Environmental impacts of global & OECD scenarios								WaterGap
World Bank (World Development Report)	*Essential*	*essential*	*essential*	*essential*	*Essential*	*desired*	*essential*	*Desired*
➲ Environmental Impacts of alternative development scenarios					IMAGE-17			WaterGap
CSD (TREND-II report)	*essential*	*essential*	*essential*	*essential*	*Essential*	*Desired*	*essential*	*Desired*
➲ Impact scenarios (through global modelling forum activities)					IMAGE-17			
FAO Agriculture Towards 2015 & 2030	*essential*	*essential*	*essential*	*essential*	*Essential*	*Required*	*essential*	*Essential*
➲ Environmental impacts of agricultural scenarios					IMAGE-17			WaterGap
➲ Land-use and climate scenarios					IMAGE-17			WaterGap
➲ Local approaches for land use, land and water					IMAGE-17			WaterGap

Appendix G. Short description of related projects

Milieuverkenningen and Milieubalans (MV & MB)

The periodic compilation of national environment outlooks and national environmental balances is a legal obligation and a core task of the RIVM. Funding comes through RIVM's core budget from the Ministry of Public Housing, Spatial Planning and Environment. The IMAGE contact persons are Eric Kreileman and Rik Leemans.

The Dutch government was one of the first to request a comprehensive national environmental assessment, including the status and prospects of the environment, an analysis of the causes, driving forces, target economic sectors, and an exploration of measures to meet environmental goals. Since, RIVM acquired an official legal status of environmental assessment office, producing an environment outlook report every few years as well as an annual assessment ('balance'), on the basis of inputs by twelve key government organisations. In addition to environment outlooks and balances, RIVM has in 1997 been given the legal task to compile similar periodic assessments on nature, for the corresponding ministries of The Netherlands.

Analysis of future ecological impacts in the national assessment concentrates on the outlooks. Four outlooks have been published since 1988. IMAGE 2 has been used to assess the worldwide ecological implications of various emission trajectories. In the fifth outlook, due July 2000, international aspects will be given a much more central role. The IMAGE-2 model cluster, in particular TES with peripheral modules, will be used to present projections of persistent environmental problems such as pressure on terrestrial biodiversity, risk to water-induced land degradation, and water stress. Regional differentiation of the impact projections is important for subsequent analysis, as the fifth outlook will explore the relation between production and consumption by the Dutch, and persistent environmental problems outside the borders of the country.

Exploring Climate Options for the Long Term (COOL)

NRP and VROM fund this project. The overall project leaders are Dr. B. Metz and Prof. Dr. L. Hordijk and the project leader of the global subprojects is Drs. M. Berk.

This projects aims to:

- Investigate options for a long-term climate policy strategy in The Netherlands in an international context;
- Contribute to the development of methods for participatory integrated assessment.

The projects organises dialogues in which policy makers, stakeholders and scientists assess options for long-term climate strategies. In this way a range of experiences and insights is included in the process.

These dialogues are executed at three levels: The Netherlands (National), Europe (Multinational) and Global. The latter focuses on the context of the UN-FCCC and at exploring long-term (30-50 year) international climate policy options and their implications for medium term policy development. At the same time the project provides insights in the international policy context to the other sub-projects of COOL (European and National Dialogue).

The COOL Global Dialogue consists of a series of international science-policy dialogue workshops to provide international climate policy makers and stakeholders from the NGO and the business community with scientific results, insights and tools relevant for evaluating and discussing long-term climate policy options and their implications for medium-term (e.g. second commitment period) decision making. These Dialogue workshops build upon extensive previous experiences, organised both prior to and since the Kyoto protocol. From 1995-1997, there has been the so-called Delft process, based on applications of the integrated climate change model IMAGE 2, that has been very successful in supporting international policy makers with information and policy tools to evaluate policy options for the Kyoto Protocol. More recently, in 1998, two science-policy dialogue workshops were organised together with Kassel University to identify key policy questions in the post-Kyoto era, such as the adequacy of present commitments, the evolution of the global climate change regime, the long-term land-use change and forestry policies and the use of policy instruments.

Central to the COOL project is a policy-driven utilisation of scientific knowledge for the evaluation of climate policy options. This means that the scientific information presented will be steered by requests for information by the participants and that each workshop will end with identifying and prioritising new request for analysis. For this reason, the dialogue is set-up as a series of workshops and we hope you are able to participate in the whole series of workshops, since continuity of participation is important for the process. The Dutch National Institute of Public Health and the Environment (RIVM), the Netherlands Bureau for Economic Policy Analyses (CPB) and their collaborative EuroPRIME partners will provide the scientific input.

Interactions between land, land use and climate

The 'Interaction land, land-use and climate' project is funded by the Dutch National Research Programme on Global Air Pollution and Climate Change. The overall project leader is Dr. Pavel Kabat (Wageningen). In this project DLO & LUW (=CCB), KNMI & RIVM (i.e. CKO) and IVM closely collaborate. The IMAGE contact person is Dr. Rik Leemans.

This project aims to investigate the role of land use and land-use change in the climate system and to quantify the consequences of, and a potential for land-use options in relation to "post-Kyoto" emission reduction and climate policies in North Western Europe. We will use stand- and landscape scale biogeochemical carbon and vegetation growth models, a regional atmospheric modelling system, a global climate model and an integrated assessment model.

The project comprises following subprojects:

i) The most important sinks and sources of CO_2, CH_4 and N_2O in relation to land-use and global change will be determined, and investigate the major uncertainties in land-use related carbon sinks and stocks in relation to the Kyoto Protocol of FCCC.

ii) A process-based assessment of land surface -atmosphere interactions will be performed at W-European scale, with some analysis extending to global scale. The RAMS model will be used to study land surface-atmosphere interactions and sensitivities at seasonal and regional scales. ECBilt model will be used on global and decadal scales. The land surface scheme of ECBilt will be improved by developing simple bulk-formulations of surface fluxes.

iii) A detailed economic analysis of the biomass production and afforestation in Northwest Europe in relation to present agricultural policies and to post-Kyoto climate polices will be performed.

iv) The integrated assessment model IMAGE-2 will be improved:

a) coupling to ECBilt;

b) improving carbon cycle- and land-use description to water and nitrogen cycle modules;

c) introducing specific carbon sequestering 'crops'; and

d) introducing improved economic cost/benefit analysis of the options for biomass fuel cycle and carbon sequestration.

v) Finally, scenarios of land-use change in relation to post-Kyoto emission reduction targets will be developed on basis of SRES. The implications of land-use option in a framework of climate-change policies will be analysed in detail by means of the improved integrated assessment model IMAGE 2, as well as directly applying modelling and evaluation tools adopted in previous subprojects.

An uncertainty analysis of IMAGE 2

This project is funded by NRP and the project leader is Dr. J. van der Sluijs. The IMAGE contact person is Dr. Rik Leemans.

This project to conduct a combined qualitative and quantitative uncertainty analysis of the integrated assessment model IMAGE 2.2. Unfortunately, it is impossible to do this for the complete model because of limited available resources and methodological and computational constrains. This analysis will therefore focus primarily on the IPCC SRES scenarios and emphasises the uncertainties in the first part of the causal chain of IMAGE 2.2 and then analyse how these uncertainties propagate through the rest of the model. Further, the analysis will primarily focus on the regional and global aggregation levels rather than on the high-resolution components of IMAGE 2. This project will not address all types and sources of uncertainty, but is restricted to uncertainties in model input, model parameters and model relations.

In a first step, we will select key model-outcomes to focus the uncertainty analysis on. Starting from these key model outcomes, the model will be subdivided into a manageable number of appropriate functional units for the uncertainty analysis. The uncertainties in these functional units will be assessed qualitatively by an expert panel applying the NUSAP methodology. The qualitative analysis will yield specific questions for a well-focussed quantitative uncertainty analysis. The results of the quantitative analysis and expert judgement will be used to rank the uncertainty of the model components. Both analyses combined should provide a comprehensive insight into the major uncertainties surrounding the IMAGE 2 model. Finally, the results of the analyses will be prepared to visualise the uncertainty of IMAGE 2 to the users community, policy makers and other NRP-projects, such as COOL to be used in their dialogue activities.

Climate change impacts on vector-borne diseases

NRP and NWO fund this project. The overall project leaders are Dr. W. Takken (LUW, Wageningen) and Dr. P. Martens (ICES, University of Maastricht) The IMAGE contact person is Dr. R. Leemans.

An increased incidence of vector-borne diseases is to be expected as a result of climate change. The projected changes in climate and climate variability will have a profound impact on the ecology of vector populations, resulting in extended duration of activity, more generations per year and higher population densities than are seen at present.

The project, which aims to give a comprehensive, integrated picture of the current status of risk of transmission of two main vector borne diseases in the world and the influence which climatic changes will have on the transmission of those diseases. The estimation of the risks of climate change on vector-borne disease transmission will entail complementary studies that simulate the effects of climate change on the distribution and epidemiology of vector-borne diseases and assess the risk to public health. Furthermore, these climatic effects will be considered in the context of confounding factors such as land-use and socio-economic variation. Knowledge from both large- and small-scale studies - i.e. development of simulation models, coupled with historical analysis and field studies in Kisumu, Kenya to assess the status quo - is used in designing measures to counteract the increased risk of disease transmission.

The IMAGE-2 team will provide different land-use and climate-change scenarios for the different model-based analyses. The models, resulting from the project will be linked to IMAGE 2 as additional impact models.

Emission Database for Global Atmospheric Research (EDGAR)

The EDGAR project is funded by the Dutch National Research Programme on Global Air Pollution and Climate Change, the Netherlands' Ministry of Housing, Spatial Planning and the Environment. The overall project leader of EDGAR is Drs. Jos Olivier of RIVM. The IMAGE contact person is Dr. M. den Elzen.

The EDGAR (Emission Database for Global Atmospheric Research) database was developed jointly with TNO within the framework of the Global Emission Inventories Activity (GEIA) core project of the International Global Atmospheric Chemistry Programme (IGAC) of IGBP. The EDGAR information system contains historical emissions of direct greenhouse gases and precursor gases and is able to provide emissions per source category both on a region and 1 degree grid basis for 1990. Version 2.0 provides global annual emissions of greenhouse gases, both per region and on a 1^ox1^o grid for 1990. The Version 3.0 is an update of the emission inventories from 1990 to 1995, and for direct greenhouse gases also to 1970, including the 'new' greenhouse gases HFCs, PFCs and SF_6.

WorldScan User Support System (WUSS)

The Dutch National Research Programme on Global Air Pollution and Climate Change funds the WorldScan User Support System (WUSS). The overall project leader and IMAGE contact person is Drs. Johannes Bollen.

The main objective of this project is to develop and analyse policy relevant stabilisation scenarios, which may serve as input to the Third Assessment Report (TAR) of the IPCC. This project will focus on the analysis of macro-economic effects of applying different policy instruments to stabilise atmospheric GHG concentrations. This analysis will be done by combining results from WorldScan and IMAGE 2. The starting point for the analysis is a new set of baseline emission scenarios, which are currently developed by the RIVM and CPB and will be included in the IPCC Special Report on Emission Scenarios. Climate policy makers will be involved in developing the stabilisation scenarios, and in this way improve the policy relevance of these scenarios. One of the problems for researchers is how to communicate assumptions and results of the stabilisation scenarios. A dedicated tool, called the WorldScan-User Support System (WUSS), will be developed to visualise assumptions and results of the WorldScan model runs. WUSS will also be designed in such a way that it will facilitate the pre-selection of scenarios to be analysed with both IMAGE and WorldScan, and therefore assists in the process of integrated assessment. Hence, WUSS can be used within the COOL project and improve the communication of integrated assessments to policy makers.

Climate variability on a decadal time-scales (ECBilt)

This project is funded by NRP. The overall project leader is Dr. J.D. Opsteegh (KNMI, De Bilt). The IMAGE contact person is M. Schaeffer.

A three dimensional coupled ocean/atmosphere/sea-ice model will be developed to study the decadal and centennial variability of the climate system and its dependence on changes in certain parameters. The model is realistic in the sense that it contains the minimum amount of physics that is necessary to simulate the mid-latitude planetary and synoptic scale circulations in the atmosphere as well as its variability on various time-scales. The oceanic model component describes both the wind driven and the thermohaline circulation in the ocean.

The model is simple as compared to complex state-of-the-art climate models. This makes it suitable to perform many long-term integrations on a workstation in a relatively short time.

The model will be used to study the predictability of climate. We will focus on the predictability of the natural variability on decadal and centennial time-scales. We will investigate how this variability depends on the choice of certain parameters that occur in the description of the hydrological cycle in the model. Those parameters appear in the parameterisation relations for evaporation, cloud formation, rainfall and sea-ice formation and melting.

Once tested the geophysical model will be handed over to RIVM. They will add a biogeochemical model and emission modules so that it can be used in the integrated assessment model IMAGE of RIVM. We will support them in this task.

AIRCLIM

AIRCLIM is funded by the European Union (Fourth Framework Programme). The overall project leaders is Prof. Dr. Joe Alcamo (University of Kassel, D). The contact persons are Dr. Max Posch Posch, Dr. Michel den Elzen and Dr. Bert de Vries.

AIRCLIM aims to provide scientific information about important policy-relevant issues concerning the linkage between regional air pollution and climate change in Europe. In this project the following questions will be addressed:

- How will climate change affect the success of policies to control regional air pollution in Europe, and vice versa?
- What is the relative importance and overlapping occurrence of regional air pollution and climate change impacts in Europe?
- What are joint targets and strategies that can effectively reduce both regional air pollution and climate change impacts in Europe?

The instrument for addressing these questions is an integrated modelling framework. This framework couples components of integrated assessment models covering global climate change (IMAGE 2) and regional air pollution in Europe (RAINS), plus additional new components.

The framework will be used to generate scenarios that explore the above questions. The scenarios will span from 1995 to 2100, with a spatial resolution ranging from the country-scale to grid-scale, and will cover the following subjects: (a) Emissions leading to regional air pollution and climate change, (b) Changes in the atmosphere including the build-up of regional air pollutants and greenhouse gases together with deposition of air pollutants and changes in temperature and precipitation, and (c) Impacts of climate change and regional air pollution. The impact assessment of climate change and regional air pollution will be based on exceedances of critical thresholds, and an "environmental balance sheet". The environmental balance sheet will compare (i) estimates of emission abatement costs and (ii) estimated geographic coverage of impacts, for various scenarios.

The project is unique in its comprehensive treatment of the linkage of these two major problems in Europe, in its simultaneous coupling of scientific and policy aspects of these two problems, and in its use of the “critical threshold” concept for both regional air pollution and climate change in a single analysis.

Greenhouse Gas Emissions Control Strategies (GECS)

GECS is funded by the European Union (Fifth Framework Programme). The overall project leader is Dr. Patrick Criqui (Institut d’Économie et de Politique de l’Énergie, CNRS-IEPE, Grenoble, F.). The IMAGE contact persons are Dr. Bert de Vries and Dr. Lex Bouwman.

The goal of this proposal is to develop global (world) scenarios in order to analyse impacts of Post-Kyoto policies under flexibility mechanisms for emission reduction including options to reduce emissions resulting from land-use change and for strengthening carbon sinks. The aim of the project is to fully analyse the spectrum of issues resulting from the mechanisms established at the Kyoto conference and furthermore extend the analysis for the post-Kyoto perspectives.

A high priority will be put on the identification of emission reduction strategies that may fit in a perspective of sustainable development at world level, i.e. that correspond to criteria of international and intergenerational equity. The research component of the project aims at enhancing and using international energy and economy models already developed in the context of preceding Framework Programmes in order to fully analyse the consequences of different patterns of international commitments and agreements for the control of greenhouse gas emissions to the 2030 horizon.

Projections in land-use change until 2030 will be based on the SRES scenario’s, using the corresponding assumptions on economic and population growth, dietary patterns, consumer preferences, agricultural practices and biofuel use. It will be explored how the resulting land-use changes at the 0.5 x 0.5 ° level can be characterised and presented in a comprehensive way. They will be compared with other projections and expectations. The presently used GHG-emission coefficients will be evaluated and adjusted to the latest insights. The result will be a series of emission profiles for the greenhouse-gases considered at the regional level and in relation to scenario assumptions.

As a follow-up to the previous activity, an inventory will be made of the cost at which land-use related GHG-emissions can be reduced per unit of activity in Western Europe, and, though less detailed, for the other world regions. This will provide the information to construct static Marginal Abatement Costs (MAC) curves, which indicate the emission reduction potentials in carbon-equivalent values. Part of the analysis will focus on the interaction between various end-of-pipe oriented emission reduction measures and on the relation with (changes in) the food system such as agro-technology, food trade and consumption patterns.

The resulting continuous MAC curves are then introduced into the dynamic model by simulating least-cost abatement strategies. In this way, for each scenario dynamic regional GHG-emission MAC curves can be constructed and compared with similar curves for the energy-industry related GHG-emissions.

LBA Carbon

LBA Carbon is funded by the European Union (Fifth Framework Programme). The overall project leader is Dr. P. Kabat (Wageningen, NL). The contact person is Dr. Rik Leemans.

Understanding the Amazonian carbon sink and how it will behave in response to future changes in CO_2 concentrations and climate requires an integrated study using a range of different methodologies and across a range of scales. To achieve this we will utilise direct tower based flux measurements of the exchange of carbon dioxide and between vegetation and the atmosphere for some key ecosystem types. These studies will be complemented at selected sites by atmospheric boundary layer measurements and intensive studies of soil carbon dynamics, investigations into the importance of losses of carbon from tropical forests in forms other than CO_2. A manipulative water-balance experiment will also be employed to evaluate the importance of predicted increases in the frequency and severity of drought events. These studies will improve understanding of how these ecosystems are influenced by the current climate.

Also using results from previous studies, the site specific and basin-wide information on plant and soil stocks and fluxes will then be synthesised using state-of-the-art ecosystem flux models and a spatially (and in some cases temporally) explicit description of the key underpinning biophysical drivers modulating ecosystem carbon balances. This will allow the current magnitude of the contemporaneous carbon sink and its inter-annual variation over the last 20 years to be better quantified.

Finally, to determine the probable future behaviour of the tropical sink, results from the basin-wide synthesis modelling study will incorporated into an integrated assessment model. By this means, effects of various feasible Amazon Basin policy scenarios on the global carbon budget with attendant socio-economic implications at both the regional (Europe & South America) and global scales will be evaluated.

Advanced Terrestrial Ecosystem Analysis and Modelling (A-TEAM)

A-TEAM is proposed to the European Union (Fifth Framework Programme). The overall project leaders are Dr. I Colin Prentice (MPI, Jena, D) and Dr. W. Cramer (PIK, Potsdam, D). The IMAGE contact person is Dr. Rik Leemans.

The aim of A-TEAM is to illustrate the importance of the likely changes in natural processes and environmental changes for the *combined sensitivity* of ecosystems. Such combined sensitivity requires investigation of ecosystem processes at appropriate spatial and temporal scales, and in a common scientific framework for natural and managed ecosystems. Once these processes are at least partially understood, the relationship between ecosystems, their sustainability and society can be addressed in a "policy exercise mode".

Complex environmental issues have previously been addressed successfully through the development of computer models as is shown by recent advances in many fields, such as in ocean-atmosphere interactions or in the eco-physiological and biophysical factors of plant growth. To address ecosystem sensitivities at the large scale and in relation to both natural processes and intensive direct human impacts, requires the introduction of a new level of complexity and sophistication. A new *modular* system for ecosystem modelling has been developed and applied to selected European ecosystems. The consortium has developed a new spatio-temporal framework for modelling ecosystem processes in heterogeneous landscapes, as well as important underlying databases. Unlike previous ecosystem models, the design of this framework permits to incorporate drivers and impacts at a broad range of spatial scales and for both managed and unmanaged systems. The model is also computationally efficient enough to allow the testing of numerous scenarios of changing environment (climate, CO_2, nutrient load) and land use at high resolution across the map of Europe.

The next stage, proposed by an expanded consortium – the A-TEAM – is to consolidate these achievements by linking the processes modelled in natural and semi-natural ecosystems to the dynamic socio-economic realities which actually define the landscape of Europe, such as a changing land-use pattern. By direct inclusion of new working groups, the

A-TEAM will also much more directly link into scientific assessments of forest growth, biogeochemical cycling and disturbance dynamics.

UNEP's Global Environment Outlook

This activity comprises RIVM's contributions to GEO-1, GEO-2 and GEO-3. The project is carried out for The Netherlands' Ministry of Public Housing, Spatial Planning and the Environment and for UNEP. Contact persons in the IMAGE-2 team are Rik Leemans and Eric Kreileman.

Global Environment Outlook reports are compiled by UNEP and 22 collaborating centres. GEO is a system of modern assessments: integrated analysis covering pressures, policy, sustainable development context and scenario-analysis. The significance of GEO to policy lies above all in regional differentiation of the global picture.

RIVM is the longest-serving GEO collaborating center. It contributes primarily:

- scenario-analysis
- policy-oriented synthesis in the reports
- strategy-development for the UNEP work area 'assessment and monitoring'
- advice on data and information

IMAGE is the core tool in RIVM's contribution to GEO. It has been used to evaluate the GEO-1 conventional development scenario in terms of environmental impacts. Particularly important has been the development of an experimental module to estimate waterstress at the appropriate scale level (IMAGE grid and drainage basins). IMAGE components applied for GEO are primarily TESS and GEO associated databases (HYDE, EDGAR and related data logistics)

GEO-3 preparations start November 15 in Nairobi. It will aim to channel the environmental input into the Rio+10 process, reporting in late 2001. Although decisions on thematic focus (if any) have still to be taken, the Executive Director of UNEP has indicated before that the potential of economic instruments needs much more thorough and broad-based analysis. Therefore, it is not unlikely that this topic will have a central place in GEO-3. In addition, global conventions are another likely area of focus (assessment of success; analysis of linkages, including ancillary benefits). For the application of IMAGE and related tools, this means a somewhat stronger emphasis on use of 'peripheral' members of the IMAGE family (WorldScan, POPHER, land degradation risk and in particular water stress) in combination with IMAGE TES.

Priority setting for an European environmental policy plan

The economic assessment of priorities for a European environmental policy plan focuses on identified Prominent European Environmental Problems (PEEPs) such as climate change, chemical risks and biodiversity. The study, commissioned by the European Commission (DGXI) to a European consortium led by RIVM, is based on chain analysis of socio-economic and environmental processes geared towards the 12 PEEPs and focusing on the economic efficiency and increased environmental effectiveness of policy actions to abate environmental damage.

The primary objective of this study is to provide an economic assessment of priorities for European environmental policy planning. In 1993, the Council and Member States adopted the general approach and strategy of the European Community Programme of policy and action in relation to environment and sustainable development (the 5th EAP), covering the period to the year 2000. The 5th EAP, 'Towards Sustainability', underscores the integration of environmental considerations into both macroeconomic and sectoral policies. The Commission has reviewed the Programme and concluded that the most important task is to set key priorities and translate further the Programme's strategy into a set of pragmatic and operational tools (COM(95)624 final and COM(95)647).

It is generally agreed that the next environmental action programme should be based on:

- economic considerations should become central to the formulation and implementation of environmental and sectoral policies;
- new policy measures should address the underlying causes of environmental problems;
- policy implementation costs should not exceed environmental benefits.

To support the preparation of the next EAP, this prospective analysis has been carried out to guide priority setting for European environmental policies. The analysis is based on an examination of the cost of avoided damage, environmental expenditures, risk assessment, public opinion, social incidence and sustainability. The study incorporates information on targets, scenario results, and policy options and measures including their costs and benefits.

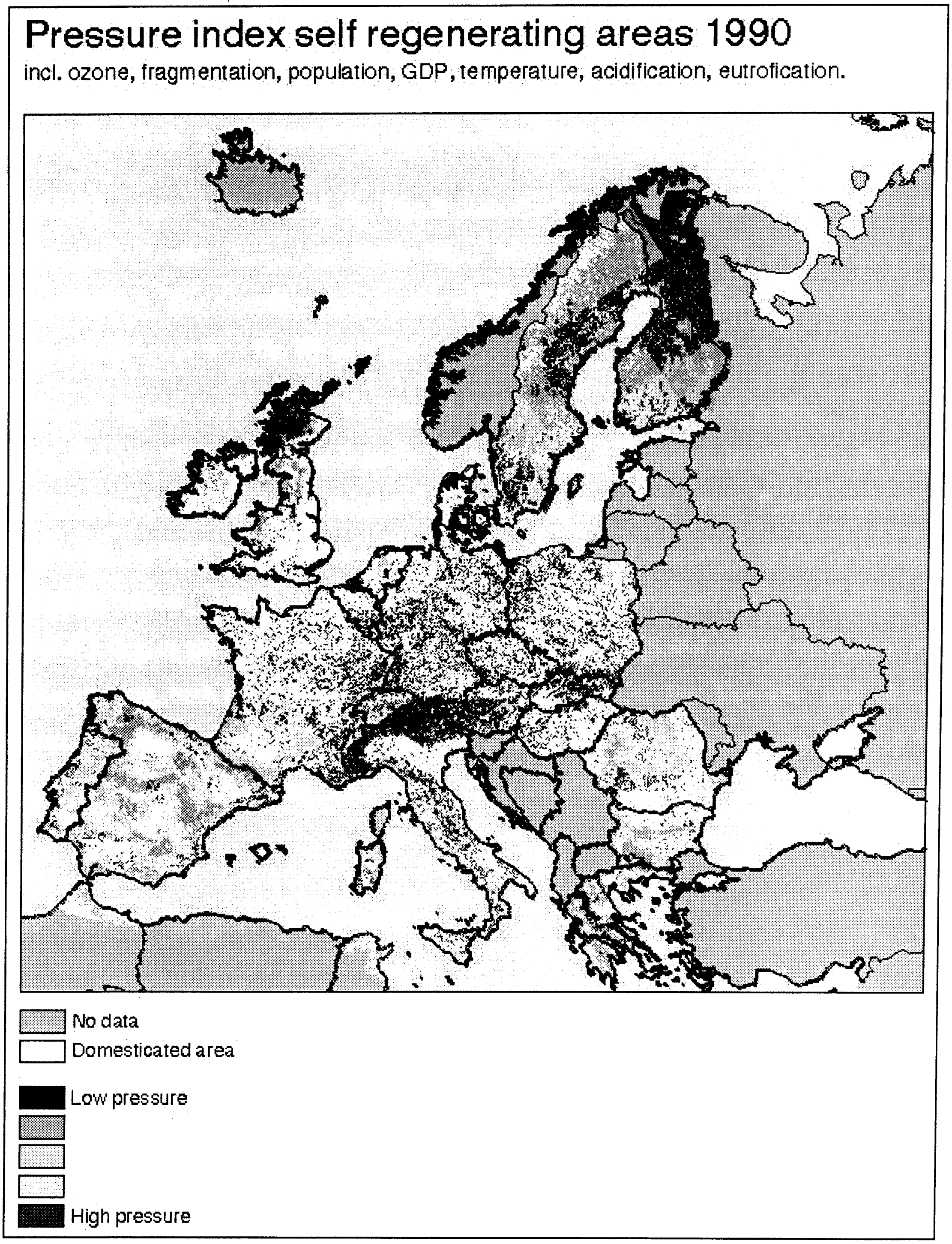

Figure 5 Pressure index for the PEEP study

Applications of the IMAGE model include the analysis of climate change (PEEP 2) in Europe according to a business-as-usual scenario, and the integration of the rate of climate change in the combined pressure on remaining natural ecosystems area (PEEP 4).

Figure 6 illustrates the use of IMAGE in the PEEP assessment through the result of the tentative analysis of pressure on self-regenerating natural areas in Europe, for the current situation (1990). The study uses the year 1990 as reference for evaluation of several scenarios for the year 2010, including a baseline scenario for continuation of current trends with no additional policy measures, a scenario for situation of maximum feasible reduction of environmental pressures and an accelerated policy scenario using new targets which go beyond current policies.

Precursors of Ozone and their Effects in the Troposphere (POET)

POET is funded by the European Union (Fifth Framework Programme). The overall project leaders of POET is Dr. Claire Granier of the Institut Pierre Simon Laplace (IPSL) in Paris (France). The EDGAR contact person is Drs. Jos Olivier.

The POET project (Precursors of Ozone and their Effects in the Troposphere), to be carried out by 8 European institutes under the 5th EU Framework Programme, will provide an accurate estimate of surface emissions of ozone precursors and of ozone response to changes in these emissions, as well as a quantification of the impact of changes in ozone precursors emissions and distributions on current and future distributions of two greenhouse gases, ozone and methane. During the project, surface emission inventories will be updated. These will be compared with inverse modelling of atmospheric global distributions of ozone precursors; observations of the isotopes of carbon monoxide and methane will be used to validate and better quantify the surface emissions. The use of different models is very important in the project, as it is the only approach, which will quantify the limitations of current models and show uniquely that results can be model-dependent.

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