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Report of the 2006 IMAGE Advisory Board

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The Netherlands Environmental Assessment Agency (MNP) functions as the interface between science and policy, producing independent assessments on the quality of the environment for people, plants and animals to advise national and international policy-makers.

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Rapport in het kort

Rapport van het IMAGE Adviespanel 2006

In 2006 voerde een internationaal Adviespanel onder leiding van professor Leen Hordijk (IIASA) een audit uit van versie 2.4 van het IMAGE-model. Hierin stonden de modellen IMAGE, TIMER en FAIR centraal. Aan de orde kwamen: wetenschappelijke kwaliteit van de modellen, hun bijdrage aan de MNP-doelstelling van het evalueren van duurzame ontwikkeling; en het onderzoeksnetwerk. De audit is uitgevoerd op verzoek van het MNP als bijdrage aan een algemene wetenschappelijke en maatschappelijke toetsing.

Over het algemeen was het oordeel op alle drie de gebieden positief, hoewel het Adviespanel een aantal zaken heeft geïdentificeerd waar urgente actie nodig is. Hieronder vallen het continuëren van het hoog gewaardeerde vermogen om beleidsrelevante geïntegreerde evaluatiestudies uit te voeren, daarbij rekening houdend met alle onzekerheden in onderliggende wetenschappelijke, technische en socio-economische processen. Een belangrijke voorwaarde hierbij is dat de beschikbare menskracht zorgvuldig verdeeld wordt tussen ontwikkeling en applicatie van het modelinstrumentarium, met een goede balans tussen mensen met een biofysische en socio-economische achtergrond. Verdere ontwikkeling van het geïntegreerde modelkader, in samenhang met nieuwe toevoegingen, om meer aspecten van duurzame ontwikkeling te omvatten, moet ingegeven worden door een beter geformuleerde MNP-brede strategie.

Naast dit advies van meer algemene aard heeft het Adviespanel een lijst van specifieke wetenschappelijke zaken opgesteld die in toekomstig werk aan de orde zouden moeten komen, samen met partners in een uit te breiden internationaal onderzoeksnetwerk.

De inhoud van dit rapport is voor volledige verantwoordelijkheid van het Adviespanel. Het MNP zal de bevindingen gebruiken bij het formuleren en implementeren van plannen voor verdere modelontwikkeling en -toepassing.

Trefwoorden: IMAGE, Integrated Assessment, Klimaatverandering, Klimaatbeleid, Modellen, Milieu, Emissies

Preface

The IMAGE Advisory Board convenes regularly to discuss, review and give advice on current and future developments and applications of the integrated assessment model for climate change, IMAGE. In the earlier stages of the project (1992 - 1995), the Advisory Board studied IMAGE 2.0 in detail and set the scene for the development of IMAGE 2.1 and its applications. The Board lost importance in the second phase of the project (1996-1999), when the policy advisors who convened in the Delft Dialogue Workshops adopted a strong advisory role in scenario applications and developments that were needed to support discussions for the development of the UNFCCC Kyoto Protocol. After this period the IMAGE team began to focus more strongly on a new model version, scientific applications and participation in the development of the IPCC emission scenarios. This recent more scientific focus required the IMAGE Advisory Board to reconvene for the third session in November 1999. On the basis of the Board's recommendations, the IMAGE team developed version 2.2 of the model, which was used for developing one of the SRES marker scenarios in 2001, and the release of the CD-ROM describing the IMAGE application to all four SRES scenarios. In the period 2001-2006 the IMAGE model was renamed: Integrated Model to Assess the Global Environment. It was applied in various global climate and environmental assessments, and new versions of the model (2.3 and 2.4) were released. With this new documented version and all the plans for further extension and improvement of IMAGE, TIMER and FAIR, a fourth session of the Advisory Board was organized from 30 October –1 November 2006 to review IMAGE, TIMER and FAIR. This session was requested by the MNP management, as part of the ongoing institute-wide review process.

This report describes the findings, recommendations and suggestions of the Advisory Board, and is the exclusive responsibility of the board. Management and staff of MNP is committed to use the report in formulating and implementing strategies for further development and application of the global modeling framework. This follow-up is strictly not part of this report.

Joop Oude Lohuis

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Summary

This report summarizes the findings resulting from the fourth session of the IMAGE Advisory Board. IMAGE version 2.4 is MNP's current model to assess the global environment. The recommendations and suggestions of the Advisory Board relate to (improvements in) the IMAGE model version 2.4, to the development of strategies for future research and development, and to the scientific and policy network of the IMAGE team.

The IMAGE model and its components and companions (TIMER, FAIR) have found much appreciation both in science and policy. The general appreciation in policy circles has been built on the scientific credibility of IMAGE. The Advisory Board commends the IMAGE team with its scientific achievements and strongly recommends that it continues to strengthen the models' scientific credibility.

Regarding strategy, the Advisory Board advises the MNP and the IMAGE team to jointly elaborate a plan and time table for implementation, to further develop IMAGE (including TIMER, FAIR and other tools of MNP such as GLOBIO), and to maintain (and if possible, improve) its status as an integrated assessment instrument. The plans to extend the domain of the IMAGE framework to analyses of sustainability issues in the GISMO project also calls for a clear strategy, avoiding risks of diverging development lines into separate models rather than a complementary, synergetic approach. Given the MNP goal of contributing to research and policy on sustainable development, widening the IMAGE team's collaboration in European and global projects is recommended.

MNP management has stated that the energy system is one of their two top priorities and the Advisory Board supports this view. The IMAGE team needs to maintain and further develop the energy and climate policy-related components of its modeling framework in order to maintain its policy relevance. However, it is not clear that the current resources allocated to energy and climate policy within the IMAGE team are sufficient for this task.

The Board suggests making a well-documented version of the model available within the research network (and examining possibilities for a wider distribution via the internet); an explicit and transparent documentation of the structure of the model, including the data flows, should be made available to enhance the confidence of users (both of the model and of results) in the model.

Analysis of the propagation of sensitivities/uncertainties through the chain of coupled model components needs the attention of the IMAGE team. In addition, the Advisory Board recommends that the IMAGE team explore probabilistic approaches to characterize uncertainties in projections from the IMAGE model family.

The Advisory Board takes a positive view of the recent cooperative PhD projects with universities but strongly recommends that explicit and unequivocal agreements with respect to the products be developed and the time of delivery secured to minimize the risk of diverging objectives of university and IMAGE team.

The Advisory Board recommends organizing sessions for reviewing IMAGE-TIMER-FAIR-GISMO every four years. Future Advisory Boards should overlap with the past Boards to achieve continuity by maintaining at least four members.

Recommendations in specific model components are:

- **Climate**. The Advisory Board recognizes the need for a dual-track approach, maintaining the climate modeling capacity (SPEEDY), on the one hand, and the use of downscaled GCM results, on the other. SPEEDY should be mainly used to explore sensitivities of model components where interactions of model components with the atmosphere could be of importance.
- **Economy.** Improvements in the economic fundamentals of the models IMAGE and TIMER (and FAIR) should be continued and form a basis for the linkage between the different models. This is particularly important for the energy system as the bulk of mitigation costs will be related to energy supply and demand. Also, the incorporation of economic competition between different bioenergy crops with other land uses in the land-use model has consequences for both the TIMER and IMAGE core models. The Advisory Board therefore supports increasing efforts to integrate models and modules developed at (and with) partner institutes into the overall framework, to reinforce and expand the links to impact models, and to develop and link an economic framework (GTAP-E). The Advisory Board stresses that diverging development lines into separate models (IMAGE, GISMO) should be avoided.
- **Energy.** The Advisory Board recommends improving the representation of energy demand allowing for an improved analysis of the potential for increased energy efficiency. Improved analysis of bioenergy in relation to other fuels, such as the suggested improved representation of energy transformation and production processes, would be useful, as well as the incorporation of economic competition between different bioenergy crops with other land uses in the land-use model. The possibilities for tighter coupling between IMAGE, TIMER and FAIR should be investigated, allowing for examining feedbacks between different model components and improving the model's reproducibility.
- **Atmosphere**. Several options for improving the atmosphere-ocean system of IMAGE should be explored, including using parameterized results from detailed chemistry models, and source-receptor matrices for computing atmospheric deposition.
- **Land use**. In the land allocation procedure of IMAGE there is a need for explicitly addressing the competition among claims on land for different uses (urban, infrastructure, and food, non-food, non-market uses).
- **Agricultural production systems**. Technology and management need more emphasis, and in the livestock sector, productivity should be related to inputs and feed quality.
- **Carbon**. With the second track EMIC work underway involving LPJ, and given the speed and efficiency of this model, it is recommended that this be incorporated into IMAGE to replace the current carbon cycle model. This would assist with overall organization of the two-track approach and provide IMAGE with a state-of-the-art model that is well established and understood by the wider research community.

1 Introduction

The Netherlands Environmental Assessment Agency (MNP) serves the Dutch government with independent assessments of the state of the environment. MNP's mission states: 'The Netherlands Environmental Assessment Agency (MNP) supports national and international policy makers by analyzing the environmental impact of policies and of trends in society. We provide independent integrated assessments of topics such as sustainable development, energy and climate change, biodiversity, transport, land use and air quality. Reports are produced both on request and at the MNP's own initiative. All our reports are available to the public.' [1]

MNP sees its role as follows: 'We supply the Dutch government and international organizations such as EEA, UN, OECD and the World Bank with sound, evidence-based assessments. We can do this because of our position at the centre of national and global knowledge networks. The MNP acts as the interface between science and policy.'

MNP uses an earth system model, the Integrated Model to Assess the Global Environment (IMAGE) as a tool to investigate global environmental problems, their causes and links in a comprehensive framework, including the major feedback mechanisms within the biophysical system. The first, single-region version, called the Integrated Model to Assess the Greenhouse Effect, was developed in the late 1980s. Since then, updates have been presented in various publications that led to the latest version, the IMAGE 2.4 framework.

MNP has asked an Advisory Board to evaluate the current version of IMAGE, TIMER and FAIR and has posed the following questions:

1. Are the models up-to-date with present scientific insights?
2. Can the new model developments contribute sufficiently to achieving the goals the MNP has set itself for (global) sustainable development?
3. Is the scientific network of collaborative research partnerships an adequate and sufficiently broad basis for continuation of the work into the future?

After a brief summary of the IMAGE model, organization and findings, in-house research and research in collaboration with other organizations in Chapter 2, the evaluation procedure will be outlined in Chapter 3. The conclusions and recommendations of the Advisory Board on general issues are presented in Chapter 4, and on specific scientific issues in Chapter 5. Finally, in Chapter 6, the Advisory Board's conclusions with regard to the three questions that were addressed to the Advisory Board, will be presented.

[1] Netherlands Environmental Assessment Agency (2006) Linking science and policy. Bilthoven, The Netherlands, 20 pp.

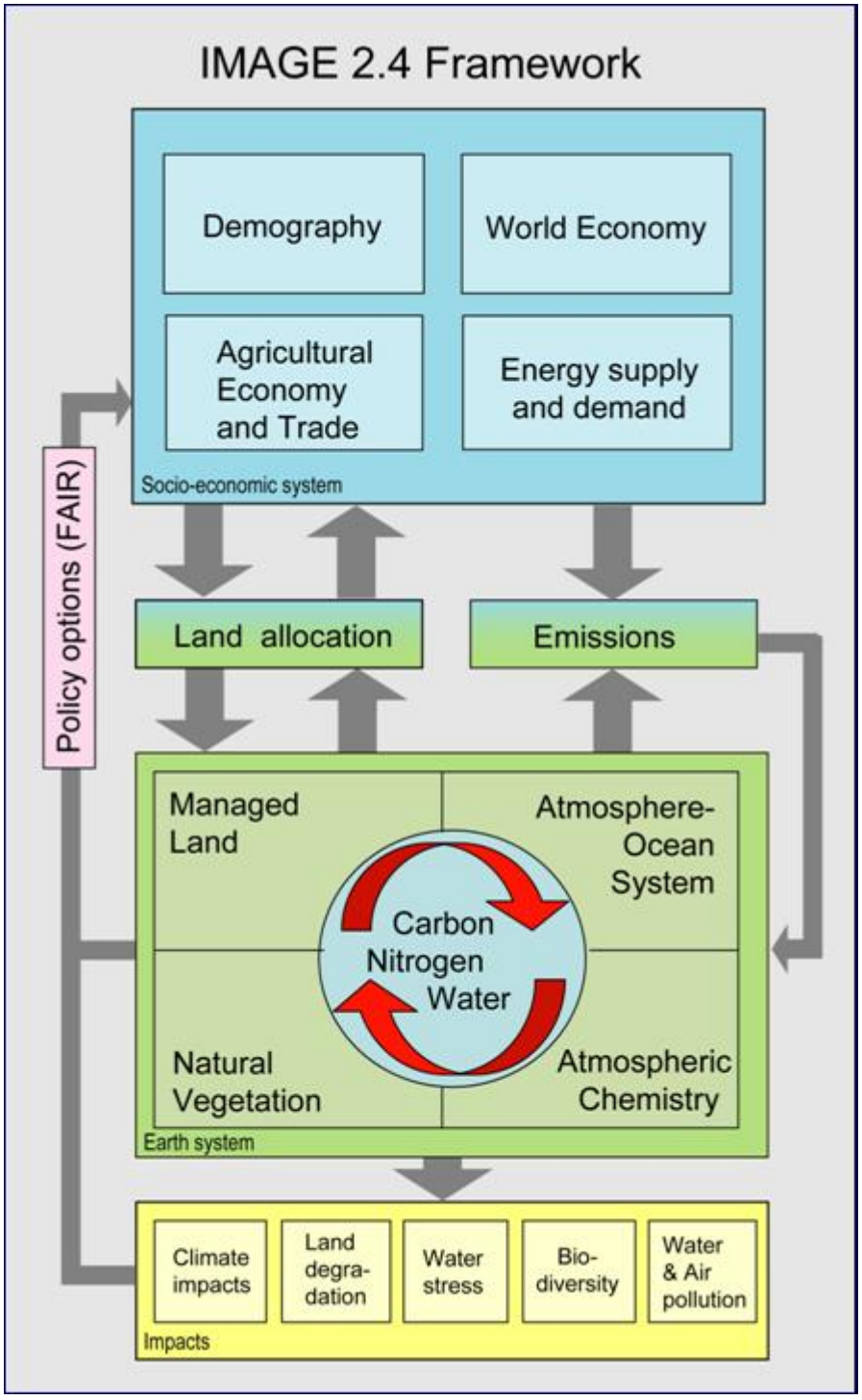

Figure 1. Scheme of the IMAGE 2.4 model.

2 The IMAGE project

2.1 Background

The versions of IMAGE 2.4, TIMER 2.0 and FAIR 2.0, reviewed by the fourth IMAGE Advisory Board, represent the result of many years of development at the National Institute for Public Health and the Environment (RIVM); work on IMAGE is continuing at the Netherlands Environmental Assessment Agency (MNP), now separate from the RIVM. MNP has been operating as an autonomous agency since 1 January 2006. The current status of the models IMAGE, TIMER and FAIR has been described in the MNP publication 'Integrated modeling of global environmental change. An overview of IMAGE 2.4', which was used by the Advisory Board as a major source of information on the models.

IMAGE 2.4 shares many of the basic structural components with its predecessors. Assuming change in population and the macro economy as key drivers, the model establishes physical indicators for both the energy/industry system and the agriculture/land-use system for assessment of changes in land cover, climate, and the carbon and nitrogen cycles. IMAGE can be used to feed broader policy-exploring tools such as the FAIR model for exploring comprehensive climate mitigation strategies (Figure 1).

Looking at the top of the scheme in Figure 1, we see a description of the driving forces, including demographics, energy supply and demand, and agricultural demand, supply and trade. All these forces interact through land use and emissions with the Earth systems. Subsequently, important elements in the biophysical modeling of land cover and land use processes are also addressed, i.e. land cover and land use, contemporaneous and historical land cover, the carbon and nutrient cycles, followed by climate and climate variability, including its interaction with land cover. Finally, the use of data and information from IMAGE as input for broader policy-exploring tools is discussed for both global biodiversity and comprehensive climate mitigation strategies and regimes. The models FAIR and TIMER are not fully integrated with IMAGE 2.4.

In the TIMER model, aggregated economic indicators, such as gross domestic product (GDP), household consumption and value added in the industry, services and agricultural sectors are used to estimate the demand for energy services. Energy supply chains with substantial technological detail in some portions are then selected on the basis of relative costs to meet the resulting final energy demand after autonomous and price-induced energy savings. Market shares for energy resources and technologies are calculated via a multinomial logit distribution function. TIMER includes explicit treatment of traditional biofuels, vintages of capital stock in the electricity sector, learning-by-doing and resource depletion. It generates primary and final energy consumption by energy type, sector and region; capacity build-up and utilization; cost indicators, and greenhouse gas and other emissions. Important new elements that have been introduced in the TIMER 2.0 model version (part of IMAGE 2.4) are hydrogen production, carbon sequestration and storage

(CCS), and more detailed descriptions of the electric power system and renewable energy, including bio-energy.

IMAGE 2.4 uses the Atmosphere–Ocean System model developed for IMAGE 2.2. However, important non-linear interactions between land, atmosphere and ocean cannot be studied with IMAGE 2.4 due to limitations of the current climate model and the natural vegetation module. Therefore, a series of studies was carried out to explore a possible pathway to include a more detailed climate model in IMAGE. As an outcome of this exploration, the detailed climate circulation model SPEEDY, coupled to the Dynamic Global Vegetation Model LPJ, will be part of future IMAGE versions. In addition to these environmental impacts of global change, calculated within the core biophysical modules, results are also used as input to drive impact models in the broader IMAGE 2.4 framework, such as the biodiversity model GLOBIO 3. GLOBIO can be used to assess the impacts of climate and land-use change, infrastructure, and nitrogen deposition on biodiversity and ecosystems. Likely effects of scenario assumptions or policy interventions are estimated by calculating trends in mean species abundance.

IMAGE results are also used for the evaluation of climate policies in conjunction with the policy decision-support model FAIR. FAIR is widely used to assess the environmental and abatement cost implications of international regimes for the differentiation of future emission reductions in greenhouse gases. The model links long-term climate targets and global reduction objectives with regional emission allowances and abatement.

2.2 Organization and funding

Work on IMAGE has, since 1 January 2006, been carried out at the Netherlands Environmental Assessment Agency (MNP), now separate from RIVM. Maintenance, development and applications of the IMAGE, TIMER and FAIR models have their basis in the team Climate and Global Sustainability (KMD), which is one of the eight teams of MNP. KMD has a total staff of about 35 persons.

Table 1. Staffing and funding of the IMAGE project, including TIMER and FAIR.

Category	MNP staff		Other cost	Total	Core MNP	Co-funded [a]
	fte	k€ [b]	k€	k€	k€	k€
1	4 [c]	520	400	920	920 [e]	250
2	4.5 [d]	585	30	615	615	
3	5	785	380	1165	965	200
Total	13.5	1890	810	2700	2500	450

[a] EU projects (50% contribution) and the national CCSP program (30%). The income is reallocated to fund research at partner institutes (joint PhD positions and subcontracts at WUR, for cat. 1. For cat. 3, external income is mostly used to subcontract other institutes.

[b] Average rate of 130 k€/fte assumed (rates decreased in 2006 from earlier years following independent status from RIVM)

[c] Excluding 1 fte on exploratory research into global SD modeling

[d] Including 1 fte temporary technical support for SPEEDY/LPJ modeling

[e] External funding does not lead to a reduction in MNP funding, see note a).

The **total effort in 2006** falls into three categories (Table 1):

1. Model development, including co-operation with network partners
2. Model integration, input data, data exchange, technical model support, programming, quality control, including model version control, and visualization
3. Model applications

Over **the period 2001-2006,** the total effort in categories 1 and 2 has remained almost stable, but the contribution from external co-funding (EU and national research programs) has increased in recent years. Increasingly, the model development efforts have focused on the two core subjects, energy/climate and land use. The effort on climate modeling in conjunction with dynamic vegetation is currently substantial, some 1.5 fte in categories 1 and 2 together.

Two new staff members will be added **for 2007**, one for applications in international energy and climate work (TIMER and FAIR) and one for applications in global sustainability assessments (IMAGE). For subsequent years, the IMAGE team expects that ongoing funding will be needed to further develop the core models, with lower investment in LPJ/SPEEDY. The team also expects that increasing efforts will be needed to integrate models and modules

developed at (and with) partner institutes into the overall framework, to reinforce and expand the links to impact models, and to develop and link an economic framework (GTAP-E).

2.3 Additional in-house research activities

For addressing the focus on sustainability, MNP has embarked on development of the Global Integrated Sustainability MOdel (GISMO). This model will be developed to quantitatively assess and analyze global sustainability questions, with a focus on the link between development and the environment. GISMO will build mainly on the already existing (global) simulation models within the IMAGE framework, but will also seek collaboration with (modeling) groups outside MNP. These groups include the University of Denver for economic modeling; the institute for Medical Technology Assessment (iMTA-Erasmus University Rotterdam) for health modeling; and the Institute for Environmental Studies (Vrije Universiteit, Amsterdam) for analyses of the role of institutions. The project does not intend to create a large new model, but rather to develop a framework to address broad sustainability issues and assess the trade-offs and co-benefits of specific policies in an integrated way. Topics to be covered include population and health, poverty and biodiversity, the role of institutions in sustainable development and vulnerability and food security.

2.4 Collaborative research

In recent years, a series of improvements, enhancements and extensions of the IMAGE model have been initiated as part of an overall model strategy fostering broader coverage of sustainable development issues. The development activities increasingly take place in close collaboration with national and international partner institutes, with the aim of jointly benefiting from shared expertise and models.

In conjunction with the dynamic climate model SPEEDY, the current BIOME vegetation model of IMAGE will be replaced by the dynamic vegetation model LPJ of the Potsdam Institute for Climate Impact Research (PIK). The LPJ model has been made available to MNP as part of a broader co-operation plan between PIK and MNP, and has been adapted to fit into the IMAGE structure. The linkage to LPJ will allow a better representation of biogeochemical cycles and analysis of the compounded effect of changes in these cycles and biogeophysical changes associated with land use and hydrology.

The intermediate complexity 3D climate model SPEEDY has, in close co-operation with the Netherlands Meteorological Institute (KNMI), been transferred to MNP to be linked to IMAGE. Following various adjustments for making this coupling operational, the model was successfully coupled with the dynamic vegetation model LPJ at MNP. Test runs confirm the proper functioning of the coupled dynamic climate-vegetation system, although a few remaining flaws still need to be dealt with. Further work will involve a coupled ocean model, already ongoing at KNMI, and integration with the IMAGE framework. This integration will

allow for capturing of changes in climate variability and their implications for other sections of the model, e.g. natural vegetation, agricultural production and the hydrological cycle. It will also enable assessment of climatic impacts of changes in radiative forcing and land use.

Wageningen University and Research Centre (WUR) now works closely together with MNP on a variety of topics. In addition, other network partners contribute their knowledge and expertise in collaborative arrangements. At the time of the review, three PhD students were involved in the development of new model components for IMAGE.

Crop modeling at the IMAGE grid scale links crop growth to climate, soil, water, nutrients and management parameters and thereby marks a substantial improvement in the current, less integrated treatment of the various processes and linkages in IMAGE 2.4. This work is carried out in a joint PhD research project with the WUR Plant Production Systems Group (PPS).

An improved and extended land-allocation module for IMAGE is being developed in a joint PhD project with the WUR-Soil Inventory and Land Evaluation Group. A country-by-country representation of drivers and parameters of future land-use determinants will be implemented, consistent with regional totals and country information from the GTAP model of the Agricultural Economics Research Institute (WUR-LEI). The main purpose is to better reflect determinants of the spatial allocation process.

Further integration of water supply and demand with other parts of IMAGE is being considered under a co-operative agreement with the WUR Centre for Water and Climate. The new model should provide a better integrated treatment of water in key processes, such as variable precipitation (SPEEDY), evapotranspiration (LPJ and the new crop model) and extraction for irrigation (the new crop model), households and industry.

3 Evaluation Procedure

3.1 Advisory Board

The Advisory Board consisted of eight members with a broad range of expertise (see Annex 1). The Board received its instructions from the MNP management (see section 1) and met from 30 October to 1 November 2006 in Hotel Heidepark in Bilthoven. Scientific staff of the IMAGE team presented the current state of IMAGE and plans for future development (see Annex 2). Members of the MNP management informed the Advisory Board about MNP's strategy and its commitment to further develop and use the IMAGE model.

The Advisory Board had access to many papers about IMAGE and its applications, including a new book in which the model is described. During the review meeting a vivid interaction between Board and IMAGE staff took place, leading to a better understanding of the IMAGE model.

The Board drafted the first version of this report during the review meeting in Bilthoven and presented its preliminary findings to IMAGE staff and MNP management.

3.2 Suggestions for future evaluation processes

The Advisory Board recommends organizing sessions for reviewing IMAGE-TIMER-FAIR-GISMO every four years. Future Advisory Boards should overlap with the past Boards to achieve continuity. Four members of the previous Advisory Board could, for example, participate in the next session, and four new members covering 'new' fields will complement the Board. Members of the Advisory Board should preferably be selected from research groups that are not closely collaborating with the IMAGE-TIMER-FAIR-GISMO projects. A good balance between the expertise of the Advisory Board members and the model (components) to be reviewed is a prerequisite.

The Advisory Board suggests organizing a separate process prior to sessions of the Advisory Board (for example, through conference calls), whereby perspectives on specific aspects of the framework (such as the economic aspects) could be collected and presented to the Advisory Board for consideration.

The presence of all IMAGE staff members during sessions of the Advisory Board is useful. However, more emphasis on the interconnections between modules and the overall uncertainties will facilitate the evaluation procedure. With increasing use and development of IMAGE by external partners, a user-survey could be organized and presented during future Advisory Board sessions.

4 General issues

4.1 Scientific credibility

The IMAGE model and its components and companions (TIMER, FAIR) have found much appreciation both in science and policy. The general appreciation in policy circles has been built on the scientific credibility of IMAGE. The Advisory Board commends the IMAGE team with these achievements and strongly recommends continuing to strengthen the models' scientific credibility.

Although the pressure on using the IMAGE/TIMER/FAIR framework for policy analysis will always be large in organizations like MNP, the Advisory Board strongly advises MNP management to continue to stimulate publications in peer reviewed journals and presentations at scientific conferences as a means to ensure the scientific quality of IMAGE.

4.2 Balance of team resources

The Advisory Board is of the opinion that there is a need to maintain an appropriate balance between the resources devoted to the biogeophysical aspects of IMAGE, which is widely recognized as one of its key strong points, and socioeconomic and policy aspects. It was felt that given the level of evident demand and likely importance of the climate and energy policy aspects over the coming years, there is a need to consider carefully whether the resources currently devoted to the socioeconomic and policy aspects are consonant with the needs.

The energy system is central to climate change policy, and is an important factor for issues of sustainability. Mitigating climate change is also fundamental to meeting sustainable development goals, particularly in the poorest and most vulnerable part of the world. To maintain its policy relevance, the IMAGE team needs to maintain and further develop the energy and climate policy-related components of its modeling framework. The state of the art in energy modeling is moving forward and it is important that the energy component of the IMAGE framework is further improved to maintain its status. MNP management has stated that the energy system is one of their two top priorities and the Advisory Board supports this view. It is not clear that the current resources allocated to energy and climate policy within the IMAGE team are sufficient for this task.

4.3 Clear development strategy

Currently, the additions to IMAGE and the use of IMAGE seem to take place on an ad hoc basis. The Advisory Board recommends that development and use of IMAGE will be brought in line with MNP's mission. MNP's mission:

'The Netherlands Environmental Assessment Agency (MNP) supports national and international policymakers by analyzing the environmental impact of policies and of trends in society. We provide independent integrated assessments of topics such as sustainable development, energy and climate change, biodiversity, transport, land use and air quality. Reports are produced both on request and at the MNP's own initiative. All our reports are available to the public.'[2]

MNP has chosen to focus on sustainable development, and thus MNP's tools, such as the IMAGE model, have to contribute to this focus. The IMAGE model, originally developed as a model for integrated assessment of climate change, has gradually been extended to an Integrated Model to Assess the Global Environment. This broadening of the scope of IMAGE is in line with MNP's broad mission, but has not yet led to a clear scientific development plan for IMAGE. In order to move from a greenhouse gas assessment model to a global environment model, the MNP leadership and the IMAGE team should develop a clear development plan, including a time path and an overview of potential collaborators.

MNP management should also better define to which policies IMAGE should provide substantial inputs, and on this basis develop and, with the funding ministry, negotiate a clear strategy for IMAGE to participate at national, European, and global fora, addressing these policies.

4.4 Level of policy interventions

The IMAGE team has contributed to numerous international assessments and policy-related fora. These include the IPCC assessment reports, the IPCC Special Report on Emissions Scenarios, UNEP Global Environment Outlooks, the Energy Modeling Forum, Millennium Assessment, Dutch Task Group Kyoto Protocol, European Commission. Participation in these fora satisfies a number of goals. This participation provides for dissemination of the work of the team; it allows the team to keep abreast of the latest developments and to foster international collaborations, and helps maintain the credibility of the IMAGE team, especially towards policy-makers. It is important that the IMAGE team continues to contribute to international assessments. The Advisory Board realizes that these contributions place a heavy demand on time and resources and that the IMAGE team will need to decide on its priorities.

The Advisory Board observed that most collaborations are at national level, which facilitates effective development of the IMAGE system. However, this might not promote use of IMAGE results in an EU-wide policy arena, where a trans-national approach is expected (European Research Area).

Therefore, the Advisory Board appreciates that some European-wide collaborations are already taking place (in two EU-funded Integrated research projects, in the EEA State of the

[2] Netherlands Environmental Assessment Agency (2006) Linking science and policy. Bilthoven, The Netherlands, 20 pp.

Environment and Outlook Report, as well as bilaterally with various institutions), but also notes that the IMAGE model is only partly participating in European impact assessment-related projects, which consider the three dimensions of sustainable development (environmental, social and economic). Participation of the IMAGE team could enhance the environmental dimension of these assessment tools. For this reason, we endorse more and closer collaboration within the European Research Arena, and enhanced work with institutions outside of Europe. Particular attention should be given to collaborations with partners from emerging economies.

4.5 Strategy for including sustainability issues

MNP has plans to extend the domain of the IMAGE framework to analyses of sustainability issues. While IMAGE can currently address a number of aspects that touch on sustainability, new components and new connections between components are necessary to address sustainability issues more directly. Health, water quality, and mortality, for example, are strongly linked. The GISMO project is currently investigating approaches to this problem, although it was unclear how this will be or is planned to be accomplished, to what extent it duplicates, complements or would be incorporated into IMAGE.

The largest possible majority of the Advisory Board finds significant promise in this area of investigation, but also a number of essential issues that need to be addressed. One approach could be the implementation of a ‘scanner’-type model analogous to FAIR that integrates results from the other components, with limited interaction using ‘soft linkages’. A possibility that might have a better chance of success than the present process would be development of a component that more tightly integrates the relevant IMAGE model components (demographics, economics, energy, land use, water) using an annual time step.

The current model structure and the operating structure of the IMAGE team allows for developing model components rather independently. All that is currently required is that certain standard inputs and outputs be provided for and/or by each component. A tighter linkage between model components, however, would provide a much greater capability to explore feedbacks between systems at the potential cost of constraining the development of individual components. Development of the appropriate architecture for coupling model components might alleviate some of the downsides of this approach, but this will require appropriate changes to project management to assure appropriate development of each component. A combination of these two approaches is also possible.

MNP and the IMAGE team need to carefully evaluate the merits of potential approaches, and consider carefully and strategically the interaction between GISMO and IMAGE. The Advisory Board is concerned that a parallel development effort might result in divergence between the GISMO project and the core IMAGE framework. A key to this evaluation is to explicitly formulate the goals of the sustainability modeling project, being more explicit in terms of the expected contributions to the analysis of the three dimensions of sustainability. Sustainability is a notably loose concept. It is necessary that MNP defines what types of

results are desired from a sustainability modeling project, also considering the goals of the core IMAGE work (such as improved representation of water), before a project can be appropriately scoped and designed.

4.6 Sensitivity analysis

Sensitivity analysis of individual model components is a useful method for increasing understanding of uncertainties in model results and can also provide significant insights into model structure and behavior. The results of sensitivity and uncertainty analyses should be provided in technical reports and papers. Such analyses also generate valuable information on where further research, data collection, and data analysis may need to be performed in order to improve analysis products. Such information should also be provided in reports and papers. While sensitivity and uncertainty analyses have been performed for some model components, their results were not always reported in the primary reports made available to the Advisory Board. Analysis of the propagation of these sensitivities/uncertainties through coupled model components also needs attention. Such analyses should be performed when it is determined that this can provide information to IMAGE team members and the policy community about the robustness of key analysis results.

4.7 Probabilistic approaches to characterizing uncertainty

The Advisory Board recommends that the IMAGE team explore further probabilistic approaches to characterizing uncertainties in projections from the IMAGE model family. Whilst this should not replace sensitivity analyses of submodels, there is an increasing demand from the policy world for probabilistic assessments of projections and of risks from climate change. In co-operation with PIK, probabilistic temperature projections were constructed using the coupled FAIR and MAGICC models.

4.8 IMAGE-framework accessibility

4.8.1 Access to the IMAGE model by other research groups

To increase confidence in performance of the model and create results for applications and/or regions for which the IMAGE-team is lacking the capacity and/or the data, the Board suggests making a well-documented version of the model available to users within the IMAGE network. Dissemination through the internet could be investigated to enhance the model’s distribution. Whether this should be the complete source code or an executable needs to be discussed. It is recognized that there is a risk that (if the source code is made available) inappropriate modifications may be introduced, leading to erroneous results; also, requests for support may interfere with smooth functioning of the team.

4.8.2 Documentation

It is the opinion of the Advisory Board that the material that was made available to the Advisory Board, including the IMAGE 2.4 book, did not allow for (or only with great difficulty) following the flow of information through the model framework, including the exchange of information between the various submodels. For future distribution of IMAGE within the research network or through internet, an explicit and transparent documentation of the structure of the model, including the data flows, should be available. Such a flow description will also enhance the confidence of possible users (both of the model and of results) in the model.

4.8.3 Distribution of datasets and results

To increase the impact of the IMAGE modeling framework, datasets could be made available to other research groups, who could use this information for modeling and to check whether results can be reproduced. An alternative approach could be to make (intermediate) model results available that could be used by others in subsequent analyses.

4.9 Concern about results from PhD projects

The Advisory Board takes a positive view of the recent co-operative projects with university groups developing and improving specific parts of the IMAGE framework. However, where these building blocks are developed in the framework of joint PhD projects, the Advisory Board strongly recommends that explicit and unequivocal agreements should be made with respect to the products to be developed and the time of delivery. The risk that objectives of the university supervisor and the IMAGE team diverge should be recognized and appropriate actions taken, as well as the risk, albeit small, of the PhD candidates discontinuing their studies.

5 Specific scientific issues

5.1 Atmosphere/climate

5.1.1 Fully coupled earth system model of intermediate complexity

The development of a fully coupled earth system modeling of intermediate complexity (EMIC) within the IMAGE framework is likely to be important for the scientific development of IMAGE as a state-of-the-art integrated assessment model. There are a number of important issues that can be addressed by this modeling framework, which an approach based on pattern scaling of GCM output can not address, although the number is judged to be limited at this stage.

On the other hand, the Advisory Board strongly believes that the main focus of IMAGE as an integrated assessment model is on the ability to use and characterize the full range of uncertainties in scientific understanding of projected climate change, and this can not be done with a single integrated Atmosphere-Ocean GCM (AOGCM). Hence, whilst strongly supporting the dual-track approach, we believe that the more traditional set-up should be used for applications that do not need an evaluation of feedback mechanisms between atmosphere-ocean and land surface. Synergies between the main track and the development of an EMIC capacity may be found through the incorporation of the LPJ model into the main track of IMAGE, where it would be driven by GCM patterns and not used in a fully coupled mode.

The Advisory Board recommends that the scientific development strategy for IMAGE includes a careful assessment of the processes required to be included within an EMIC, in particular, in the atmosphere GCM, in order to fulfill the integrated assessment role of IMAGE. Atmospheric chemistry, air pollution and related issues, variability, extremes and coupled feedbacks, in particular, need to be carefully examined.

5.1.2 Climate modeling

The Advisory Board recognizes the need for a dual-track approach, maintaining the climate modeling capacity (SPEEDY), on the one hand, and the use of downscaled GCM results on the other. SPEEDY should be mainly used to explore sensitivities of model components where interactions of model components with the atmosphere could be of importance, such as for assessing the impact of changing climate variability on agricultural production systems, natural vegetation and seasonal use and availability of water resources and problems of water stress. Also, the possible impacts of changing vegetation patterns on climate (variability), a relatively new and, to date, hardly covered by large GCMs, can be looked at with the coupled models.

The Advisory Board does not recommend making substantial improvement to the SPEEDY model, since it is probably already rather detailed compared to other IMAGE components. An exception is to establish the link of model radiation to regionally resolved pollutants resulting from emissions in the IMAGE model. The Advisory Board recommends careful adjustment of cloud parameters in SPEEDY to ensure the best possible fit of results with present day climate.

5.1.3 Explore existing/emerging approaches to scale extreme events

As an integrated assessment model, it is important that IMAGE retains the capacity to characterize the range of uncertainties in the projections of future climate change under arbitrary scenarios. Appropriate scaling from global mean scenarios to regional climate statistics from projections of different GCMs is therefore a key part of this ability and IMAGE needs to maintain state-of-the-art abilities in this area, using, *inter alia* the IPCC AR4 generation of AOGCM output.

Improvements in AOGCM models and understanding of basic processes has led to improved characterization of changes in extreme events under future climate change and this has been reviewed in the forthcoming IPCC WGI AR4 report. One of the insights from this assessment is that a number of different types of extremes relevant to impact modeling, scale with forcing to a significant degree. At the same time, the importance of extremes for impacts on water, ecosystems, food production, etc. is increasingly recognized in the literature. We recommend therefore that the IMAGE team explore approaches to incorporating scaling of extreme events for different climate scenarios into the IMAGE framework.

5.1.4 Improve the description of atmospheric chemistry and aerosols

The Advisory Board recommends substantially improving the current description of global averaged O_3 (and its precursors) and aerosols, which it considers to be too simplistic, and which does not allow for evaluation of regional effects on climate and air pollution. Several options should be explored, including using parameterized results from detailed chemistry models. Similarly, for aerosols, simplified production and removal parameterizations may be derived from one or more of the models participating in the AEROCOM project. In section 5.3 we recommend using this improved analysis for assessing impacts on (agro-)ecosystems.

5.1.5 Incorporate source-receptor matrices for N and S deposition

The Advisory Board recommends staying in close touch with the experiments currently performed within the frame of the Task Force on Hemispheric Transport of Air Pollution (TF HTAP), which aims at generating source-receptor relationships for ozone, and aerosol components and depositions, which eventually could be incorporated in the IMAGE model.

5.2 Energy component

The energy component of the IMAGE framework, or TIMER, has improved substantially since the last review. The energy supply sector, in particular, has been updated to include specific energy supply technologies. The linkage between TIMER and the core IMAGE model yields enhanced capability in terms of biomass supply. The linkage between TIMER and FAIR provides a complete framework for policy analysis that includes multi-sector mitigation options (energy system, carbon plantations, and non-CO_2 greenhouse gases). Work with the IMAGE model, drawing heavily on the energy component, has been used in a number of international assessments. Participation at this level would not have been possible without the improvements made so far. Recent work on biomass with carbon capture and storage, for example, is among the leading efforts in this area. The IMAGE-TIMER model combination performs well amongst its international peers and, on this basis, can be considered state-of-the-art.

Improvements in the energy component can be made in a number of areas. The IMAGE team has identified a number of areas of potential improvement. Of these, the Advisory Board finds several notable. As most models in its class, TIMER focuses on energy supply. Improvements in the representation of energy demand would also be highly beneficial, as this would allow an improved analysis of the potential for increased energy efficiency.

The analysis of bioenergy is currently a strength of the IMAGE system; further enhancements in this area will be needed to maintain this position. Improved analysis of bioenergy in relation to other fuels, such as the suggested imposition of the improved representation of energy transformation and production processes, would be useful. Also useful would be the incorporation of economic competition between different types of bioenergy production and other land uses in the land-use model.

The FAIR model has improved significantly since 2000, e.g. inclusion of the multi-gas and cost-models, with widely recognized relevant uses for policy analysis at the Dutch, European and international levels. These include effectiveness, efficiency and equity analysis of Post-2012 climate regime alternatives, the EU 2 degree target, and historical responsibility questions arising from the Brazilian proposal for the UNFCCC.

The inclusion of air pollution abatement costs into the energy component would allow an economic analysis of the co-benefits of climate policy. Such a capability would have significant policy relevance.

5.2.1 IMAGE-TIMER-FAIR coupling

The current structure of ‘soft coupling’ TIMER and FAIR with other model components has the advantage of allowing separate development of the energy component without interfering with the other model components. However, it has the distinct disadvantage that possibilities for examining feedbacks between the energy and land-use system are limited. Improvements in the economic fundamentals of the models IMAGE and TIMER (and FAIR) should be continued, and form a basis for the linkage between the different models. The Advisory

Board therefore supports increasing efforts to integrate models and modules developed at (and with) partner institutes into the overall framework, to reinforce and expand the links to impact models, and to develop and link an economic framework (GTAP-E). The Advisory Board stresses again that diverging development lines into separate models (IMAGE, GISMO) should be avoided.

This coupling of models using GTAP-E as a basis for linking would allow further feedbacks to be examined. In addition, tighter coupling will improve the reproducibility. The team should investigate structural options that would allow tighter coupling, but also maintain the ability to develop and run the energy component separately. Improvements in the economic fundamentals of these models should be continued. This is particularly important for the energy system as the bulk of mitigation costs will be related to energy supply and demand.

5.2.2 Non-energy abatement costs

With the indigenous TIMER model, good abatement cost information in the energy sector is available for the FAIR model. Non-energy abatement costs (agriculture, industry) would benefit from further work to bring the most recent developments in this area into the modeling framework.

5.3 Agriculture/Land use

5.3.1 Technology generation for crops and grassland

The Advisory Board recommends that the agricultural crop, managed pasture and soil simulation module currently under development should allow, for any location and any crop (species), simulation of different crop production technologies, each with its own yield and set of management practices. The module should have a global perspective from the beginning to ensure that representations of temperate, subtropical and tropical agricultural crops and managed grasslands are well-balanced from the start. The module should be designed in such a way that it allows integration into a common framework of the water, nitrogen, carbon and phosphorus balances across natural and managed systems

5.3.2 Linkage between agro-ecological and agro-economic aspects of land use at grid scale

The Advisory Board is of the opinion that land-use allocation at the regional level should be governed not only by physical criteria, such as yield potential and water availability, but also by economic considerations, such as (for instance) land productivity, labor productivity, or land conversion costs. Such a formulation should allow reflection of economic competition among different land uses, such as production of bio-energy, production of animal feed, infrastructural/urban, and nature development in order to allow investigations of regional trade-offs in land use and the influence of potential policy instruments on these patterns.

The proposed procedure for land-use allocation, currently under development, should allow exploration of economic mechanisms that influence land use, for example, for identification of policy instruments to influence landscape change. Possible aims of such instruments include the reduction of tropical deforestation or preservation of natural resources, cultural landscapes and biodiversity.

5.3.3 Linkage between IMAGE and the agro-economic module with regard to non-food products

The Advisory Board is of the opinion that the linkage between the agro-economic module and the IMAGE framework should provide options for introduction of more functional relations between the economy and land use in the model, for instance, for economic valuation of non-food biomass products, not only in the form of animal feed and/or bio-energy, but also for nature values. Such a connection should allow selection of 'new' or 'alternative' land-use activities, although such 'products' are currently not part of trade flows between regions. The criteria to be used for land allocation should be defined in such a way that opportunities exist to select different production technologies, which may require development of some alternative form of land use allocation at regional level.

5.3.4 Account for feed quality in computing productivity and excretion of domestic animals

The Advisory Board appreciates the efforts devoted to quantification of animal production systems in the current IMAGE version, which has substantially improved the quality of its land-use component. However, animal performance is determined not only by the *quantities* of feed that are available to the animal, but equally by feed *quality* in terms of energy and protein content. There is an enormous difference in quality between forage crops, such as alfalfa and grass, on the one hand, and crop residues on the other. Although the Advisory Board recognizes the data limitations, it recommends taking into account the quality of different feedstuffs in calculating the feed requirements from animal production. This may be derived from the crop growth simulation that in addition to dry matter also provides the nitrogen (and thus protein) content. For most roughages, energy content (on the basis of digestibility) can also be derived from nitrogen content. Excretion of nitrogen in manure can also be derived from feed intake and composition.

5.3.5 Consistent computation of use of crop residues

The Advisory Board recognizes the importance of crop residues in global environmental assessments through their role in soil organic matter accumulation and soil carbon sequestration, their contribution to animal feed supply and their current and potential role in bio-energy production. In view of these different functions, crop residues in the model should be treated consistently and transparently.

5.3.6 Include air-pollution effects on crop production and natural vegetation

The Advisory Board recognizes that several types of air pollution can influence crop production and that this is an important issue for the integrated assessment aspects of IMAGE. Examples are ozone (especially relevant for cereals and irrigated crops) and the role of dimming of sunlight by aerosols, influencing the intensity of photosynthetically active radiation (PAR), directly influencing crop growth and yield. Although more uncertain, air pollution may have similar effects on natural vegetation and these should be explored as the science matures. Eventually, IMAGE should strive to have a spatially resolved description of ozone and aerosol pollution to allow a parameterized evaluation of air pollution effects on crops.

5.3.7 Costing of climate change and adaptation

An important element in climate policies is the consideration of the relative costs of the climate change impacts, adaptation and mitigation. The IMAGE team should consider collaborating in the production of estimates of the economic costs of climate change and adaptation. This would be particularly valuable in areas, such as the agricultural sector, where the spatial detail within IMAGE provides unique capabilities.

5.4 Aquaculture and fisheries

Fish production is a significant food source in many regions and the practice of aquaculture is expanding, both in the ocean and in coastal areas. Aquaculture can have a significant impact on nutrient flows and creates demands for feed and water. The expansion of the IMAGE framework into nutrient management and water areas should include consideration of aquaculture and fisheries.

5.5 Carbon cycle

Given the evolution of the state-of-the-art in carbon cycle and terrestrial biosphere modeling since the last IMAGE Review, the Advisory Board believes that it is now appropriate to replace the present model with a comprehensive terrestrial carbon cycle model. With the second track EMIC work involving LPJ underway, and given the speed and efficiency of this model, it is recommended that this be incorporated into IMAGE. This would assist with overall organization of the two-track approach and provide IMAGE with a state-of-the-art model that is well established and understood by the wider research community. The IMAGE team should develop an appropriate strategy for the incorporation of a research model into a policy assessment framework given that the goals of the two types of model can be different.

5.6 Water

5.6.1 Evaluate need for using subgrid distribution

In the proposal presented for development of a water supply module, it was indicated that it might be necessary to subdivide grid cells, for taking account of the heterogeneity in soil types (soil physical conditions), with the associated differences in crop water availability. The Advisory Board is of the opinion that the need for such a subdivision should be thoroughly evaluated before the procedure is implemented in the IMAGE framework. Especially when water availability is used as a criterion for land-use allocation, a careful assessment should be made of the pros and cons of such a subdivision.

5.6.2 Establish the capability to link water stress to population, agriculture, energy, and economy

The IMAGE water module should be developed to allow an integrated assessment of the effects of regional and sectoral water stress on the economy, the energy sector, agriculture, and demography. This requires, on the one hand, a commitment to computing water-related parameters suitable for use in other IMAGE modules, and on the other the expansion of these models to be reactive to limitations in water availability due to changes in climate, land use and socioeconomic water demand.

6 Questions to the Advisory Board

6.1 Are the models up-to-date with present scientific insights?

The IMAGE model and its components and companions (TIMER, FAIR) have found much appreciation, both in science and policy. The general appreciation in policy circles has been built on the scientific credibility of IMAGE. The IMAGE model has been used in a number of international assessments, some drawing heavily on the land component of IMAGE, others on its energy component. Participation at this level would not have been possible without the improvements made since the review in 1999. The IMAGE-TIMER-FAIR model combination performs well amongst its international peer models and, on this basis, can be considered state-of-the-art. The land use/agriculture component of IMAGE was also improved since the last review by implementing different production systems in the livestock sector, and by adding the nutrient flows in these systems.

The Advisory Board strongly recommends continuing to strengthen the models' scientific credibility by further improvement and development of several model components:

- **Climate**. The Advisory Board recognizes the need for a dual-track approach, maintaining the climate modeling capacity (SPEEDY), on the one hand, and the use of downscaled GCM results on the other.
- **Economy.** Improvements in the economic fundamentals of the models IMAGE and TIMER (and FAIR) should be continued and form a basis for the linkage between the different models. This is particularly important for the energy system as the bulk of mitigation costs will be related to energy supply and demand. The Advisory Board stresses that diverging development lines into separate models (IMAGE, GISMO) should be avoided.
- **Energy.** The Advisory Board recommends improving the representation of energy demand, bioenergy in relation to other fuels, improved representation of energy transformation and production processes, and the incorporation of economic competition between different bioenergy crops with other land uses in the land-use model. The possibilities for tighter coupling between IMAGE, TIMER and FAIR should be investigated, allowing for examining feedbacks between different model components and improving the model's reproducibility.
- **Atmosphere**. Several options for improving the atmosphere-ocean system of IMAGE should be explored, including using parameterized results from detailed chemistry models, and source-receptor matrices for computing atmospheric deposition.
- **Land use**. In the land allocation procedure of IMAGE there is a need for explicitly addressing the competition among claims on land for different uses (urban, infrastructure, and food, non-food, non-market uses)
- **Agricultural production systems**. Technology and management need more emphasis, and in the livestock sector, productivity should be related to inputs and feed quality.
- **Carbon**. With the second track EMIC work involving LPJ underway, and given the speed and efficiency of this model, it is recommended that this be incorporated into IMAGE to replace the current carbon cycle model. This would assist with overall organization of the two-track approach and provide IMAGE with a state-of-the-art model that is well established and understood by the wider research community.

6.2 Can the new model developments contribute sufficiently to achieving the goals the MNP has set itself for (global) sustainable development?

As the goals that MNP has set for itself are not very clearly formulated, the Advisory Board found it difficult to formulate a definite ‘yes or no’ to this question. As has been pointed out in the preceding sections, the Board advises that MNP and the IMAGE team jointly elaborate a plan and timetable for implementation to further develop IMAGE (and probably other tools of MNP such as GLOBIO) into an integrated assessment instrument for sustainable development.

6.3 Is the scientific network of collaborative research partnerships an adequate and sufficiently broad basis for continuation of the work into the future?

The Advisory Board compliments the IMAGE team for having broadened its network since the last review. Connections to Wageningen University and to KNMI in the Netherlands and to PIK in Germany have intensified and seem to be productive. Given the MNP goal of contributing to research and policy on sustainable development, widening the IMAGE team’s collaboration in European and global projects is recommended.

Annex 1 Short bio's of the Advisory Board members

Leen Hordijk (Chairman)

International Institute for Applied Systems Analysis, Laxenburg, Austria

Professor Hordijk is currently Director of the International Institute for Applied Systems Analysis (IIASA), in Laxenburg, Austria. Prior to joining IIASA, he was Director of the Wageningen Institute for Environment and Climate Research (WIMEK) in the Netherlands and Professor in Environmental Systems Analysis at Wageningen University and Research Centre. He was Chairman of the Social Science Research Council of the Netherlands Organization for Scientific Research (NWO). Leen Hordijk pioneered the development of methods for linking environmental science and economics for integrated assessments of air pollution problems in Europe. His approaches are recognized as among the most effective ever developed for linking science and policy in international environmental affairs.

Keigo Akimoto

Research Institute of Innovative Technology for the Earth (RITE), Japan

Keigo Akimoto received ME and PhD. degrees from Yokohama National University in 1996 and 1999, respectively. He received the Peccei Scholarship from the International Institute for Applied Systems Analysis (IIASA) in 1997. He joined the Research Institute of Innovative Technology for the Earth (RITE) to work with the Systems Analysis Group in April 1999. Currently he is a senior researcher at RITE. He was also a visiting researcher at IIASA in 2006. His scientific interests are in modeling and analysis of energy and environment systems, including costs, risks and public perceptions. He has worked on the research project of PHOENIX (Pathways toward Harmony Of Environment, Natural resources and Industry compleX). Supported by the Japanese government, it focuses on the integrated assessment of climate change, the impacts on agriculture, water resources, human health, ecosystems, abrupt changes etc. and mitigations.

Frank Dentener

Joint Research Centre (JRC), Ispra, Italy

Dr. Dentener is currently a research scientist with the Climate Change Unit of the European Commission Joint Research Centre, working on global-regional scale modeling of air pollution and climate issues. Since September 2002 he is project- and action leader, responsible for the coordination of scientific activities of the Climate Change Unit, for development and monitoring projects on regional and global air pollution and climate change, to ensure sound science and policy basis for these projects, and to develop and maintain contacts with the scientific community, and supervision of Ph.D. students and Post-Docs. His current research focuses on global and regional photochemical and aerosol processes, air

pollution and climate, the nitrogen cycle, and their interaction and representation in global atmospheric models. Model results are used to design optimized policy strategies to reduce both the emissions of climate gases and air pollution.

Daniel Deybe

European Commission, Brussels

Daniel Deybe has a background in agronomy and a PhD in Economics from the Sorbonne University. He has been working on modeling the agricultural sector in several countries for many years. Before being seconded to the Research Directorate of the European Commission, he was the head of the Economics, Policies and Market program at the Center for International Cooperation in agriculture research for development (France). At the Commission, he has been following projects related to Sustainable Development and Impact Assessment, in particular, in the field of multifunctional land uses. Previous working experiences include the National Institute for Agricultural Technologies from Argentina, the Inter-American Cooperation Institute for Agriculture (OEA), and Washington State University (USA). He has also done consultancy work for the US Agency for International Development, Food and Agriculture Organization, the World Bank and the Inter-American Development Bank.

Bill Hare

Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany

William Hare is a physicist and environmental scientist with nearly twenty years experience in international environmental policy, particularly in relation to the science, impacts and policy responses to climate change and stratospheric ozone depletion. He is a Visiting Scientist at the Potsdam Institute for Climate Impact Research and is on paid secondment from Greenpeace International, where he worked as Climate Policy Director from July 1992, responsible the organization’s contribution to the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol negotiations. He has contributed to the IPCC assessment processes, both as an expert reviewer and as contributor to the IPCC Special Report on Emission Scenarios, and as a lead author for its Assessment Report Four (AR4) on Working Group III (Mitigation) and on the Synthesis Report (Article 2 of the UNFCC and long-term issues). He also serves on the scientific advisory group to Tyndall Research Centre in the UK. Prior to 1992 he was Research and Policy Director for the Australian Conservation Foundation, where he directed a major Australian Federal Government policy project on Ecologically Sustainable Development and was environmental adviser on the Australian Government delegation to the Intergovernmental Negotiating Committee that negotiated the United Nations Framework Convention on Climate Change.

Wolfgang Lucht

Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany

Wolfgang Lucht is co-Chair of PIK's Research Domain on Earth System Analysis. He studied physics at the University of Kiel, where he obtained his PhD with a dissertation on energetic particle scattering in interplanetary magnetic fields. From 1994-1998 he was a post-doc at the Department of Geography and the Center for Remote Sensing at Boston University, working on albedo science algorithms for NASA's environmental satellite sensor MODIS. In 1996 he was appointed Research Assistant Professor of Geography at Boston University. Since 1999 he is at the Potsdam Institute for Climate Impact Research (PIK), where from 2001-2006 he was head of a federally funded young investigators research group on Climate, Carbon and Vegetation (CVECA). Since 2003 he is the PIK Research Group Leader for the Global Biosphere, which includes coordination of the continued development of the LPJ Dynamic Global Vegetation Model. In 2005 he was appointed Research Professor of Biosphere Dynamics and Earth System Research at the Institute of Geoecology, Potsdam University. His interests are in global biogeochemical vegetation modeling, earth observation, biosphere-geosphere co-evolution and sustainability.

Steve Smith

Joint Global Change Research Institute (Pacific Northwest National Laboratory and the University of Maryland), Maryland, USA

Dr. Steven J. Smith is a scientist at the Joint Global Change Research Institute (Pacific Northwest National Laboratory and the University of Maryland). His research focuses on long-term socio-economic scenarios and the interface between socio-economic systems and the climate system in the areas of aerosols/greenhouse gases, energy efficiency, renewable energy, the carbon cycle, and land-use changes. Recent research focuses on the role of non-CO_2 forcing agents in policy scenarios, including sulfate aerosols, black carbon, and non-CO_2 greenhouse gases. Smith is one of the developers of the ObjECTS framework, a new object-oriented modeling framework. Prior to joining PNNL in 1999, Dr. Smith worked with Dr. T.M.L. Wigley as a Project Scientist at the National Center for Atmospheric Research. Dr. Smith was a lead author for the Special Report on Emissions Scenarios and has also served on the Panel on Public Affairs of the American Physical Society and the Executive Committee of the APS Forum on Physics and Society. He received his PhD in physics from the University of California at Los Angeles. Smith was also principal investigator for the PhD Careers Project, which examined the careers of PhD physical scientists using a combination of qualitative (ethnographic) and quantitative (survey) techniques.

Herman van Keulen

Plant Research International, Wageningen, Netherlands

Herman van Keulen gained an MSc in Soil Science at Wageningen Agricultural University and Ph.D. thesis at Wageningen University in 1975 on ‘Simulation of water use and herbage growth in arid regions’. From 1994 till 1998 holder of the Chair in ‘Sustainable Animal Production’ and head of the Section Animal Production Systems in the Department of Animal Husbandry at Wageningen Agricultural University. He holds the position of senior research scientist ‘Nutrient management and sustainable land use’ in the Business Unit Agrosystems Research of Plant Research International, the research branch of the Plant Sciences Group of Wageningen University and Research Centre (WUR). Since 1999, holds a Chair in the Group Plant Production Systems in the Department of Plant Sciences of Wageningen University, and is staff member of the C.T. de Wit Graduate School of Production Ecology and Resource Conservation. His main research interests at the moment center around nutrient management in the framework of sustainable land use; he is involved in development-oriented projects in S.E. Asia (rice-based cropping systems), West and East Africa, related to the development, testing and application of crop-growth simulation models and optimization models in the framework of land-use analysis and land-use policy formulation for regional development.

Annex 2. The program of the meeting

Image review meeting, 30 October-1 November 2006

30 October

8:30-9:15 Meeting Advisory Board members

9:15-9:30 Welcome (Klaas van Egmond)

9:30-9:45 Introduction of participants (Advisory Board members and MNP staff)

9:45-10:15 Overview of IMAGE development (Tom Kram)

10:15-10:30 Coffee/tea

Progress for different model parts

(presentations of 15 minutes unless indicated otherwise)

10:30-12:00 Population, Economy and Energy

- Macro-economy (Ton Manders)
- People in the pixel (Henk Hilderink)
- GTAP-IMAGE (Hans van Meijl)

12:00-13:00 Lunch

13:00-14:00 Energy and climate policy

- TIMER, uncertainty analysis, energy/industry emissions (Detlef van Vuuren)
- FAIR (Michel den Elzen)

14:00-15:30 IMAGE-Land and C and N cycles

- Land cover, grazing systems (Elke Stehfest)
- Land use and nutrients (Lex Bouwman)
- Carbon cycle (Jelle van Minnen)

15:30-16:00 Coffee/tea

16:00-17:00 IMAGE Atmosphere en Ocean (AOS)

- Atmospheric chemistry, ocean model (Bas Eickhout)
- LPJ-SPEEDY (Bart Strengers)

17:00-18:00 Recent, current and future applications of IMAGE (Tom Kram)

(incl. SRES scenarios, EuRuralis, MA, Mitigation scenarios)

31 October

9:00-10:00 Impact modules and scanners

- GLOBIO (Rob Alkemade)
- Global Integrated Sustainability Model (GISMO) (Henk Hilderink)

10:00-10:30 Future plans

- Overview (Tom Kram)

10:30-11:00 Coffee/tea

11:00-12:30 Future plans

- IMAGE-water (Hester Biemans)
- Crop modeling (Frank Ewert)
- Land allocation (Peter Verburg/Kathleen Neumann)

12:30-13:30 Lunch

13:30-14:00 Brief summary of discussions (Tom Kram)

15:00-15:30 Coffee/tea

From the coffee break in the afternoon on day two onwards the program includes discussions led by Advisory Board on topics of the first and second day and report writing.

1 November

Discussions Advisory Board, report writing

Presentation of results of the review