PBL Netherlands Environmental Assessment Agency

IMAGE STRATEGY DOCUMENT 2015-2020

Detlef van Vuuren, Tom Kram, Elke Stehfest

June 2015

PBL 2015

IMAGE STRATEGY DOCUMENT 2015-2020

The Hague/Bilthoven, 2015
PBL publication number: 1797

Corresponding author
Detlef.vanvuuren@pbl.nl

Authors
Detlef van Vuuren, Tom Kram and Elke Stehfest

Acknowledgements
The authors would like to thank all members of the IMAGE team in writing this report. Moreover, they would like to thank members of the PBL management for their constructive suggestions and feedback on earlier drafts of the strategy. Last but not least, the authors would like to thank members of the IMAGE advisory board for their suggestions and comments on the current status of the IMAGE model and the intended strategy for future model use and improvement.

Production coordination and English-language editing
PBL Publishers

PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analyses in the fields of the environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making, by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. We conduct solicited and unsolicited research that is both independent and always scientifically sound.

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Summary

Context

The current document describes the new research and development strategy for the IMAGE Framework, for the 2015–2020 period, based on current and emerging research and policy questions. The document sets out the directions; in terms of concrete activities, the strategy will need to be updated and elaborated further, over time, and translated into annual work programmes. As discussed in this document, the core IMAGE model (mostly dealing with land use/land cover, energy, climate and the earth's environmental system) successfully has become part of a suite of models and analysis tools within PBL, referred to as the IMAGE framework for integrated assessment. The strategy described here is relevant for this framework as a whole.

The 2015–2020 IMAGE strategy aims to continue the position of the IMAGE assessment framework as one of the world's leading Integrated Assessment Modelling frameworks, suited to describe the main 21st century challenges with respect to energy, land use, climate change and biodiversity, and their interactions.

Process

The document was developed during a process of about one year which consisted of the following steps: 1) brainstorm discussions between and among the IMAGE team, related PBL research teams and PBL management; 2) development of an interim version of the strategy (June 2014); 3) discussion on the IMAGE 3.0 model (Stehfest et al. 2014) and future research ideas during the meeting of the IMAGE Advisory Board (July 2014), resulting in the report by the Advisory Board; and 4) finalisation of the strategy document, again in consultation with the IMAGE team, other PBL research teams and the PBL management

Main focus of IMAGE over the 2015–2020 period.

The IMAGE modelling framework forms an integrated assessment model (IAM) of global environmental change in interaction with human development. This means that the IMAGE framework is intended to provide an integrated view on trends that determine global environmental change (the drivers), the state of the global environment itself and the impact of future changes for the earth and human systems. In this context, the objectives for the modelling framework can be described, in generic terms, as: 1) to assess the main interactions between the human system and the earth system on a global level and over large timescales; 2) to indicate the importance of various processes of change by showing the consequences; 3) to explore various response strategies for global environmental problems and their implications; and 4) to support policy-making processes and international

assessments by providing relevant scenarios, with explicit attention for the extent and relevance of uncertainties along the chain.

The main clients of IMAGE include the Dutch Government, the European Commission, international organisations, such as IPCC, UNEP and OECD, and the research communities. In the future, efforts will be made to expand this client base to sector and business associations. The 3 leading questions for the IMAGE framework over the following years remain similar to those of the past period:

- What are effective response strategies for climate change, going beyond global cost-efficiency?
- What response strategies would be able to provide sufficient food for 9 billion people around 2050, while conserving biodiversity and the provisioning of goods and services by ecosystems?
- What levels of effort are associated with implementing currently formulated sustainable development objectives (SDGs/Planetary Boundaries)? Can multiple targets be achieved at the same time?

In addressing these questions, work on and with the IMAGE Framework will focus more on the following directions:

a. Response strategies and concrete interventions
b. Feedbacks and linkages between model components
c. Linkages between global environmental problems and human development
d. Guide policymakers and researchers on the role of uncertainty in complex environmental problems

The prioritisation is based on the observation that, over the past few years, there have been important changes to the context of IAM work: 1) a shift from problem identification to interest in the efforts and benefits of response strategies; 2) increasing interest in the governance aspects and the role of various actors; 3) increasing attention for the relationship between various problems, calling for more integration; 4) renewed attention for the relationship between human development and global environmental change; and 5) increasing interest in the IAM work, in general.

Advisory Board

In 2014, the external Advisory Board reviewed both the current IMAGE 3.0 model and an earlier draft strategy document for the 2015–2020 period. The report of the Advisory Board has been a helpful input in the development of this document. Especially regarding the long-term research focus, the operational strategy and the considerations regarding collaboration and staffing. Both the Advisory Board and PBL concluded that it would be helpful to set up a more regular interaction between them. A detailed response to the Advisory Board's suggestions and recommendations is included in this document.

Model development

As part of the consultation process, a list of required model improvements was established consistent with the overall strategy describe above. This action can be summarised in six clusters of activities.

a. Modelling key linkages in the nexus between land, energy and water
b. Emphasising the link between global environmental change and human development
c. Modelling long-term food security and integrated land-use strategies
d. Exploring plausible climate response strategies.
e. Focusing on land-based mitigation
f. Describing energy systems for the 21st century.

In addition, attention will be paid to uncertainty analysis in various components of the model and the framework, as a whole.

Operational issues

- *Quality assurance* (QA). Attention for the quality assurance over the past years will be continued by: 1) strengthening the QA for linkages within the modelling framework; 2) data quality – including those of collaborating partners; and 3) consolidation of software and programming skills.
- *Transparency and documentation*. The model documentation on the internet (wiki) will be further developed – among other things, by providing a better link with the underlying publications describing model structure and equations. The IMAGE team will also pursue a policy to allow transparency in key model inputs and outputs via the online data portal and the website.
- *External advice*. The IMAGE teams will set up more regular contact with the Advisory Board, also including representatives of IMAGE users and clients.

Cooperation and staffing

- *IMAGE within PBL*. IMAGE, more and more, has become 'the IMAGE framework' consisting of various PBL models, with the IMAGE model proper (integrating energy,

food, land use, climate, air pollution and water) at its core. Cooperation between various PBL teams is therefore essential. To facilitate this, an important basis for IMAGE activities is formed by the IMAGE team meetings. These meetings consist of regular project meetings to discuss and monitor concrete actions and progress (e.g. concerning land representation), and overarching PBL-wide meetings to ensure cooperation between related PBL research teams and to ensure that strategic development and applications are kept on track. Close involvement with the projects and priorities of the strategic multiannual programmes of Climate and Energy Transition and Biodiversity, Food and Development (SMJPs) is important for effective planning of related IMAGE work.

- *Collaboration*. The aim is to further strengthen collaborations with key partners, also based on the AB's advice. In support of this, the collaboration strategy will be elaborated further with respect to key issues, such as how to organise collaboration and ensure quality control. Key partners include Utrecht University, LEI and the Wageningen University and Research Centre, and European institutes (PIK, IIASA, FEEM). Furthermore, active participation in global activities will be continued, such as in the Integrated Assessment Modelling Consortium (IAMC), the Energy Modelling Forum (EMF), AgMIP and ISI-MIP.
- *Staffing*. Over the years, staffing of the IMAGE project has increased with respect to temporary staff, but permanent staff numbers have nearly halved over the 2007–2014 period. Clearly, a continuation of this decline would have a negative impact on maintenance and quality control. To restore balance, it is recommended that the number of more senior staff working on IMAGE is increased.

1 Introduction

The IMAGE integrated assessment modelling framework has been applied and developed at PBL Netherlands Environmental Assessment Agency (and its predecessors) since the late 1980s. Originally, the model concentrated on the causal chain of climate change as a single research issue, whereas, over time, the focus has shifted towards an assessment of future global environmental change processes increasingly within the context of the even wider notion of sustainable development. The latest version of the IMAGE model, IMAGE 3.0, was released in the first half of 2014 (Stehfest et al. 2014). The model documentation of this new version was published in the form of a new IMAGE book and a wiki-based website. The release of the IMAGE 3.0 model version also marks a moment to evaluate the IMAGE strategy at PBL.

The current document describes the new research and development strategy for the 2015–2020 period, based on the current understanding of main research questions for the next few years. The document mostly provides a direction/vision; clearly in terms of concrete activities the strategy will need to be updated and elaborated in time. As discussed further in this document, the IMAGE model proper (mostly dealing with land-use/land cover, energy, climate and the earth environmental system) has over time become part of a set of integrated assessment models and analysis tools within PBL (referred to as IMAGE framework). Examples of coupled models include for instance the biodiversity model GLOBIO and the sustainable development model GISMO. As most relevant questions are all comprehensive, the cooperation between various elements of the IMAGE framework is intended to be developed further in the future. The current strategy therefore describes ambitions of the overall IMAGE framework, while specifically indicating development consequences for the IMAGE model itself. Development strategies for other components of the framework (e.g. GLOBIO) will be elaborated in separate strategic documents. Implementation of the strategy will require resources and expertise; hence, priorities will need to be set and choices to be made, accordingly.

This strategy document was developed during a process of about one year that consisted of the following steps (a more detailed description is provided in Annex A):

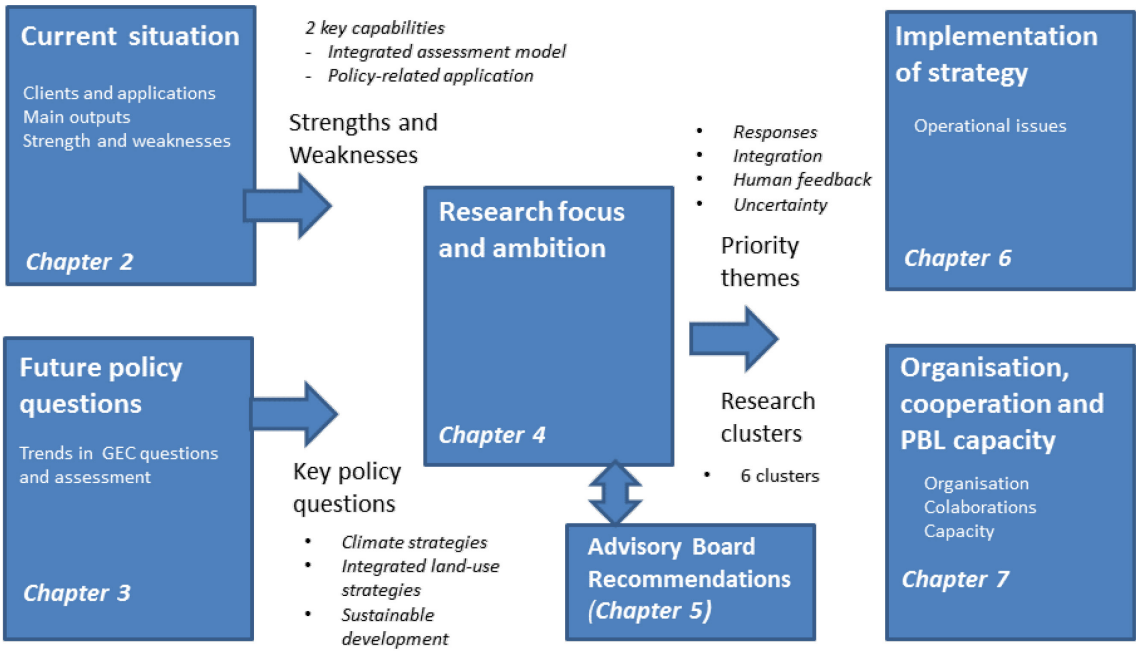
- Brainstorm discussions between the IMAGE team, related PBL research teams and PBL management on future research focus and model development (November 2013 to June 2014)
- Development of the interim version of the strategy (June 2014).
- Further discussion on the IMAGE 3.0 model and future research ideas during the meeting of the IMAGE Advisory Board (July 2014) and its resulting report.
- Finalisation of the strategy document, again in consultation with the IMAGE team, and PBL management.

As part of the strategy, this document provides an answer to the following questions:

1. What is the current status of the model? What are the current strengths and limitations of the IMAGE model, with respect to answering questions, and compared to other integrated assessment models? (Chapter 2)
2. What are the questions to be answered using the IMAGE model in the future? What policy questions will arise over the next 5 years, what questions do we want or need to answer using the IMAGE model? Who will be our main clients? (Chapter 3)
3. What are the consequences of this strategy for the research focus and ambitions of the IMAGE team? Given this question and the current status of the model, what should be the focus of research and model development over the next 5 years? (Chapter 4)
4. How can this strategy be implemented? How should the IMAGE work be organised, in practical terms? Are there consequences for the infrastructure and quality management? (Chapter 6)
5. What is the organisation and cooperation strategy? How do we organise our work? With whom do we collaborate, and why? (Chapter 7)

This process is further illustrated in Figure 1.1.

Figure 1.1 Structure of the Report



This structure implies that, in Chapter 2, the focus is on the current model – including the overall objective of the IMAGE modelling framework as it has been applied and developed, so far. Chapter 3 discusses some of the key future policy questions that are of critical

importance to further model development. Chapter 4 describes the research focus and modelling ambitions. Chapter 5 summarises the Advisory Board's advice and the way it has been addressed in this report. Chapters 6 and 7 further elaborate on Chapter 4, in terms of an implementation strategy for operational issues and the organisation of the research both within and outside PBL.

2 Current status of the IMAGE model

2.1 Objectives of the IMAGE modelling framework

The IMAGE modelling framework forms an integrated assessment model (IAM) of global environmental change. This means that the IMAGE framework is intended to provide an integrated view on trends that determine global environmental change (the drivers), the state of the global environment itself and the impact of future changes. In this context, the objectives for the modelling framework can be described, in generic terms, as:

- To assess the main interactions between the human system and the earth system on a global level and over large timescales.
- To indicate the importance of various processes of change by showing the consequences and associated uncertainty levels.
- To explore various response strategies for global environmental problems and their implications.
- To support international assessments by providing relevant scenarios.

There are also other IAM models with similar objectives. In the past, the IMAGE modelling framework has established itself as one of the world's leading integrated assessment teams (with a scope and scientific status comparable to those of, for instance, IIASA's MESSAGE team, PIK's REMIND/MAGPIE team, PNNL's GCAM team and NIES'AIM team). The current strategy is aimed at retaining this status.

Box 2.1 History of the IMAGE model

In terms of the history of the model, various phases can be identified:

- IMAGE 1.0. Single global model, focused at the climate change problem. Identification of relevant long-term dynamics.
- IMAGE 2.0. Geographically explicit model: 0.5 x 0.5 grid for the natural system and 13 model regions. Focus on the climate change problem, but in relation to a detailed land-use system.
- IMAGE 2.2–2.4. Geographically explicit model. 0.5 x 0.5 grid for the natural system and 18 to 26 model regions. Focus on broader environmental change. More comprehensive coverage of the energy system. Active participation in many international assessments.
- IMAGE 3.0. Further development of the land system by including new elements for the biosphere, carbon cycle, land allocation, and water. Further development of the energy system by including more physical representation of the energy demand

2.2 Main clients

The IMAGE model addresses several user groups. There are several ways to describe the various applications of IMAGE and the various types of clients. They can be distinguished according to the type of questions they ask and by the differences in client–research interaction. Based on this criterion, four main model applications and clients can be identified:

1. Broad research projects, mostly financed via EU framework programmes
2. International environmental assessments (such as those by IPCC, OECD and UNEP)
3. More specific, commissioned studies (specific clients and research questions)
4. PBL studies

Table 2.1 provides a summary of applications in each of these categories. The success of the IMAGE model in the past is illustrated by the list of applications in each category, including the list of EU-funded projects, the participation of IMAGE researchers in various international assessments and the application of IMAGE for specific users, such as DG Environment and DG Climate.

Table 2.1: IMAGE applications per type of client

Category (main clients)	Main examples	Main role of IMAGE
1) EU DG Research projects	ENSEMBLES (2004), MATISSE (2005), ADAM (2006), COMBINE (2009), AMPERE (2011), LIMITS (2011), PEGASOS (2011), ADVANCE (2013), FOODSECURE (2013), LUC4C (2014)	• Scenario input for earth system models • Analysis of climate policy strategies • Analysis of food system policies
2) International assessments	IPCC: - Special Report on Emission Scenarios (Nakicenovic and Swart, 2000) - Representative Concentration Pathways (van Vuuren et al., 2011) - Assessment Report WG1, WG2 and WG3 (e.g. Clarke et al., 2014; Fisher et al., 2007) Millennium Ecosystem Assessment (Carpenter et al., 2005), Global Environmental Outlook (UNEP, 2007, 2012) OECD Environmental Outlook (OECD, 2008, 2012) Agriculture Assessment (IAASTD, 2009) Global Biodiversity Outlook (CBD, 2010)	• Providing long-term scenarios as the starting point for analysis • Analysis of response strategies
3) Commissioned studies	GLIMP (Kram et al., 2012) Resource Efficiency (van den Berg et al., 2011) Various studies for DG-Climate (e.g. Rao et al., 2008)	• Analysis of global environmental change problems and response strategies • Support of climate policy
1) PBL studies	Growing within Limits (PBL, 2009) Roads from Rio (PBL, 2012) The Protein Puzzle (Westhoek et al., 2011)	• Exploration of change and response strategies

It is also possible to distinguish the IMAGE framework in terms of application areas. In that case, it is possible to distinguish 3 main areas of IMAGE application. Table 2.2 briefly summarises important uses of the IMAGE models based on this categorisation and the typical questions addressed in such studies:

1. Climate policy strategies
2. Land-use scenarios
3. Fully integrated studies

Table 2.2: IMAGE applications per category and associated clients

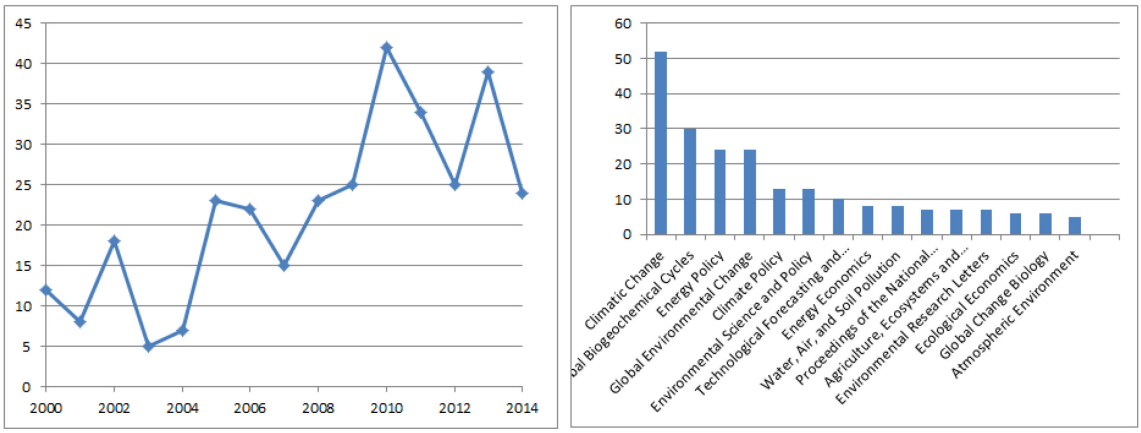
Category	***Typical questions***	***Important clients (largely in order of use over the last years)***
Climate policy strategies	• What is the technology portfolio for reaching the 2 °C target? • What are the costs of achieving various climate targets, under various assumptions? • What are the contributions of various regions to climate policy? • What is the contribution of land-related mitigation options? • What are the implications of policy strategies for emission profiles, over time?	IPCC, EC, OECD, science, I&M, Dutch Ministry of Foreign Affairs (BuZa)
Land-use scenarios	• How can we feed 9 billion people in 2050? • What impacts do dietary shifts have on global biodiversity? • What is the impact of land-use scenarios on biodiversity?	CBD, OECD, science, EC
Sustainable development/fully integrated assessment	• How can a set of sustainable development targets be achieved by 2050, and what are the main synergies and trade-offs?	OECD, BuZa, EC, UNEP, Dutch Ministry of Infrastructure and the Environment (IenM), science

Based on the first classification, we briefly discuss some of the key outputs of the IMAGE team over time: 1) scientific output; 2) participation in international assessments; 3) commissioned studies; and 4) PBL studies.

Scientific output

The IMAGE team, over the years, has also produced a steady stream of scientific articles in support of scientific research and to prove the scientific quality of the model. Over the last 4 years, the average annual number of scientific articles published was 35. The most important journals in which IMAGE results were published included Climatic Change, Global Biogeochemical Cycles, Energy Policy, Global Environmental Change and Climate Policy. The IMAGE team also published in PNAS, ERL, Nature, Nature Climate Change and Science. This reflects the quality of the work as most IMAGE applications aim to be policy-relevant. The papers are related to the various topics identified above. About 55% of the papers are related to energy and climate policy strategies, 20% to land-use scenarios, 10% to fully integrated studies, and 15% to studies regarding the imbalance of nutrient cycles. Many IMAGE team members regularly publish in scientific journals and have an h-index above 10. Scientific relevance of the IMAGE project can also be seen in the involvement of IMAGE project team members in scientific journals, and international programmes, such as the Integrated Assessment Modelling Consortium, the Working Group on Coupled Models and Global Carbon Project.

Figure 2.1 Number of articles published annually by IMAGE team members (left graph) and number of papers per journal over the 2000–2014 period (right graph)



Participation in international assessments

A particularly strong point of IMAGE, based on its wide scope and flexibility as a simulation model, is its contribution to scenario development for various international assessments. Van Vuuren et al. (2012) presents an overview of the most important international assessment studies that used scenarios, published over the 2000–2010 period. This overview shows that many of them (UNEP's GEO3, GEO4 and GEO5; the Millennium Ecosystem Assessment, the OECD Environmental Outlook, the International Assessment on Agricultural Science and Technology Development, the Global Biodiversity Outlook, IPCC and GEA) used IMAGE scenarios as their main modelling framework (in the last two cases in conjunction with other IAM models).

Commissioned studies

Most of the commissioned IMAGE studies, over the last decade, have been funded by European Commission directorates (DG Environment and DG Climate) or Dutch ministries. Compared to those in the previous two categories, the focus of these studies is more on a single issue.

PBL studies

In addition to the studies that are commissioned, IMAGE is also regularly used in PBL research projects. Such projects can be either rather specific (e.g. the impact of dietary change) or broad in scope (e.g. how to comply with a wide range of sustainable development goals for 2050, simultaneously).

2.3 Position of IMAGE, including strengths and limitations

Integrated assessment models

There are several types of models used for analysing global environmental change and human development issues. Given the complexity of the issues at stake, these models have chosen different strategies for dealing with them. Based on this strategy and the particular aim of the model, this is mostly about finding the right balance between transparency, complexity and simplification. Various groups of models relevant for global environmental change research can be identified, in relation to these strategies:

- *Earth system models*, in general, describe the full complexity of earth system processes with the aim to further scientific understanding (and with strong simplification of the human system).
- *Computable general equilibrium models* (macroeconomic models), in contrast, focus mostly on the representation of economic consequences for the near term (detailed analysis of economic impacts of environmental policies, combined with simplification of the interaction with the earth system).
- *Integrated assessment models* provide a balanced representation of both earth and human systems and to describe their interaction.

Main characteristics of IAM models, including IMAGE, are:

- **Simplification** (focus on meta-relationships)
- **Integration** (focus on the relationship between various topics; in particular between the earth and the human system)
- **Policy relevance** (IAMs support policy decisins)

Most IAMs focus on long-term processes of both earth and human systems (e.g. technology change, changes in consumption patterns, environmental degradation). Different classes can be identified within the group of IAMs, although the models also have so many individual characteristics that there is a strong overlap between these models:

i. Cost-benefit analysis models (e.g. FUND, MERGE, DICE). These models provide full-circle representation of environmental change; human activities lead to environmental degradation, which in turn also leads to economic damage. While these models, thus, are highly integrated, they combine this integration with a large degree of simplification of both human and earth systems, in order to remain sufficiently transparent.
ii. Energy system models with climate system representation (TIAM). This category includes energy optimisation models that are coupled to a climate system. To some degree, some of the larger IAM models also originate from this category.
iii. Process-oriented energy/land IAM frameworks (MESSAGE/GLOBIOM, REMIND/MAGPIE, AIM, GCAM, IMAGE). For the models in these frameworks an intermediate complexity representation was chosen of the human system (economy, energy and land use) and the earth system (climate, land cover and biogeochemical cycles).

Characteristics of IMAGE as an integrated assessment model

Clearly, IMAGE forms one of the IAM models in category iii and, in fact, can be regarded to have been one of the models pioneering this approach. This can be directly seen from the current model structure (Figure 2.1) which shows a wide coverage of various topics, a focus on energy use and land use, and a detailed representation of the earth system. Compared to

other IAMs (in categories i to iii), the IMAGE model also has a very high resolution. In terms of geographical representation, the model has 26 world regions for the socio-economic system and a detailed grid. On a temporal scale, the model operates mostly on a 1 year step resolution. The resolution is also high in terms of consumer classes, energy technologies and crop categories. The strengths and limitations of the IMAGE framework can also be compared to those of other IAMs. Several of these 'limitations' simply result of the modelling philosophy and strategy and are, therefore, not necessarily areas for improvement. It is our understanding that models should not become 'models of everything', to avoid them becoming too complex and losing focus. In that sense, it is useful to see the position of IMAGE within the context of a wider set of models in the field of global environmental change assessment.

Compared to other integrated assessment models, the IMAGE approach can be summarised as follows:

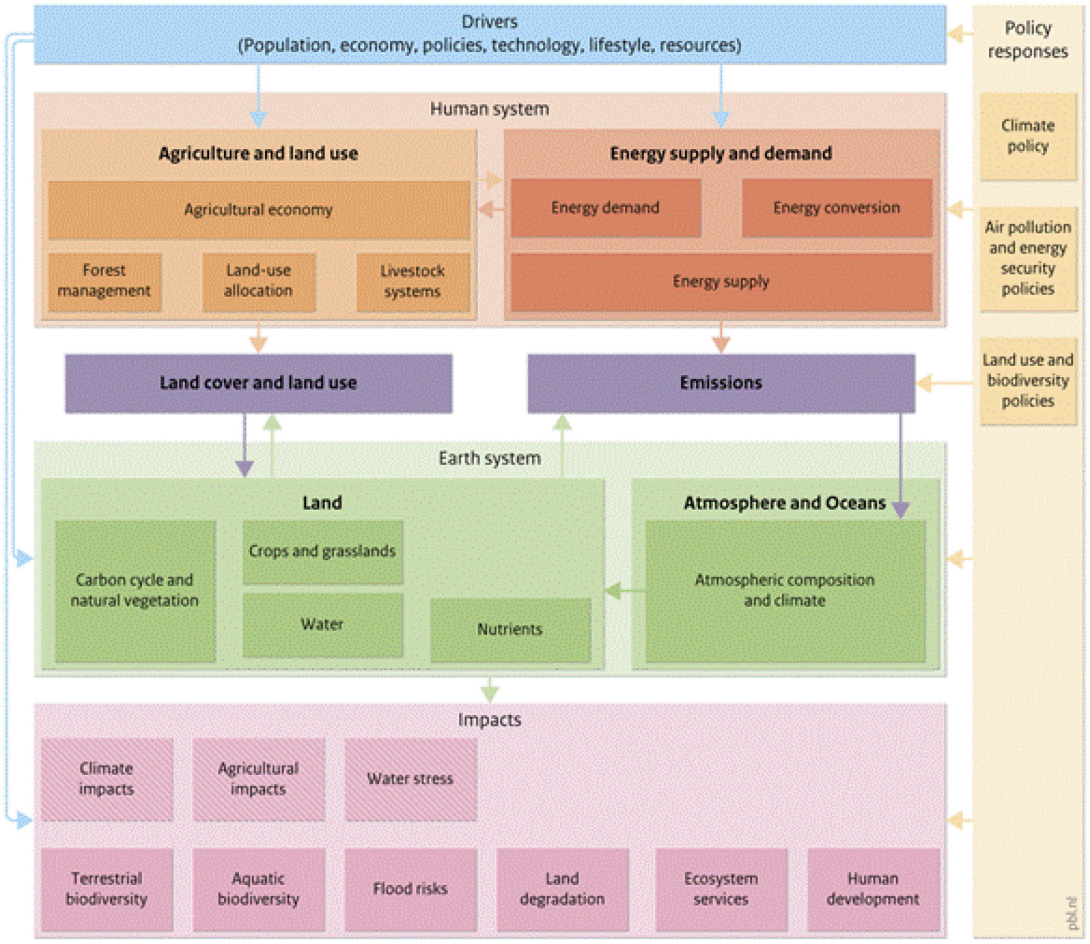
- Strong focus on representing both the earth and human systems, in terms of physical indicators. The advantage is that this allows for an easier link with the drivers of environmental degradation and a meaningful representation of long-term dynamics. As a result, also human activities are preferably represented in terms of physical units (e.g. number of cows) than in terms of monetary units.
- IMAGE is a simulation model (not an optimisation model), which makes it specifically suitable for exploring the full range of scenario analyses.
- IMAGE contains a balanced representation of the land-use/agricultural system and the energy system. The team also has a long tradition in coupling these two systems.
- The IMAGE model contains detailed representation of the variables that are useful in environmental assessments (e.g. emissions, land use, energy system).
- A key component of the IMAGE model is its geographical detail. It represents the human system for a large number of regions and includes a detailed grid for environmental system calculations.

The IMAGE modelling framework also has certain limitations, namely:

- Not all sub-models of IMAGE contain an explicit representation of policy measures. For instance, emissions are determined by so-called emissions factors (EFs, Emissions = EF x activity); as these are abstract, the model is not suitable to evaluate the feasibility of emission reduction strategies. The management factor determining future agricultural yields currently also is rather abstract.
- There is limited feedback from the environmental system to the socio-economic system. For example, there is no feedback on population growth or economic growth assumptions.
- Not all of the main linkages between the various issues are included. For example, there is no feedback from water scarcity to energy decisions.
- Some IMAGE sub-models form part of one large model code implying that they can exchange information in every time step, whereas others are coupled via the exchange of data files (e.g. the way TIMER and MAGNET are coupled to the other models in the IMAGE framework). This provides more flexibility – but is also more risky in terms of model management and limits the ability to take any feedback into account.
- The IMAGE model has a limited representation of short-term macroeconomic dynamics. Currently, price-responses are represented in the energy system model, but any feedback on economic structure, for instance, is lacking. Economic feedback is represented in the coupled MAGNET (agro-economic model).

- IMAGE is a simulation model: Policy optimisation, therefore, is normally done by using methods that run the model, interactively, multiple times evaluating the outcomes on the basis of preset criteria.
- Not all possible bio-physical feedback is represented in the model. In particular, certain very local feedback, or feedback that involves more complex mechanisms is difficult to represent in IAMs.

Figure 2.2 Overview of the IMAGE model (numbers refer to chapters in the IMAGE 3.0 model documentation)



The IMAGE model forms part of a larger modelling framework used by PBL to address global environmental issues. The larger framework also contains models such as GLOBIO (biodiversity) and GISMO (sustainable development). The IMAGE 3.0 documentation also covers the related models. This strategy is intended to promote further integration across PBL's various international models and the associated research teams. As such, the more generic strategy (overall objectives and focus) applies to the framework as a whole. The strategy, in term of concrete actions, also focuses on the core IMAGE model, as specific actions for other framework components are addressed elsewhere (GLOBIO development programmes).

2.4 Conclusion

The previous section has shown that the IMAGE integrated assessment modelling team has two key capabilities:

- IMAGE represents a comprehensive modelling framework on global environmental change. The strengths of the modelling framework can be characterised in the following terms: 1) orientation on physical changes; 2) simulation model; 3) large amount of geographical detail; 4) balanced description of energy and land use.
- IMAGE can be flexibly used for scenario analysis. As an IAM model, these analyses need to be focused on policy relevance, integration and transparency.

3 Main focus questions for IMAGE over the next 5 years

3.1 Focus questions

Section 2.1 describes the generic aims of the IMAGE framework, which can be summarised as follows: 1) to assess the main interactions between the human system and the earth system; 2) to indicate the importance of various processes; 3) to explore various response strategies; and 4) to support international assessments by providing relevant scenarios. In order to further specify the focus of IMAGE applications and development for the next 5 years, we have tried to assess recent changes that are relevant for the main focal questions. These questions are discussed in Section 3.2., on the basis of the trends, insights into the policy questions that address global environmental change problems, and the position of the IMAGE model. The policy questions, as shown in Box 3.1, are critically important for IMAGE model applications over the next 5 years.

Box 3.1: Focus questions for IMAGE (2015–2020)

- What would be effective response strategies for climate change (going beyond global cost-efficiency)?
- What response strategies could provide sufficient food for 9 billion people by 2050, while conserving biodiversity and providing ecosystem goods and services?
- What levels of effort would be needed to implement currently formulated sustainable development objectives (SDGs/Planetary Boundaries)? Can multiple targets be achieved simultaneously?

Similar questions were explored by using IMAGE in previous years. However, it is the intention to increase the policy relevance by focus more explicitily on response strategies and options, and on the impacts for human well-being and development. These types of angles will become the focus of attention for applications and to support model development over the next five years (see also Chapter 4). Table 1 further elaborates on the three focus questions in this context.

Table 3.1: Key focal questions for IMAGE development and application over the 2015–2020 period

Focal question	Key sub-questions	Key clients / policy processes
• ***What would be effective response strategies for climate change?***	○ How do costs and benefits of climate strategies compare (not necessarily in monetary terms)? What implications do long-term climate targets (e.g. the 2 °C target) have for short-term decisions and investments, also for various global regions? What are the synergies and trade-offs between climate response strategies and other issues? ○ What is the role of energy efficiency compared to that of energy supply change? ○ How fast can transformation processes occur? ○ What are the key actors involved in specific strategies? What are their interests? And how does this relate to model scenarios? ○ What are the implications of the various response options? ○ What could strategies based on specific measures contribute (non-optimal strategies)? ○ What role could adaptation play as part of effective strategies to respond to climate change?	UNFCCC climate negotiations, IPCC assessments, DG Climate Action, Dutch Ministry of IenM
• ***What strategies could provide sufficient food for 9 billion people, while conserving biodiversity and providing ecosystem services?***	○ What could be the contribution of yield improvement? Could clever land planning strategies reduce environmental pressure? What could be the contribution of measures to change diets and reduce food losses? ○ What are the consequences of yield improvement? ○ What could be the contribution of the livestock sector, via systemic shifts and efficiency improvements? ○ What would be the role of key actors in these transformation processes? What are their interests and how does this relate to model scenarios?	CBD (strategic planning), GBO assessment, DG Agriculture (strategic planning), FAO, OECD (outlook)
• **What levels of effort would be needed to implement sustainable development objectives (SDGs/Planetary Boundaries)? Can multiple targets be achieved simultaneously?**	○ What would be the trade-offs and synergies between sustainable development strategies for various environmental and development goals? ○ What would be the potential in particularly difficult areas, such as the ambition to restorable balance in nutrients cycles? Could we reduce water scarcity?	CSD, World Bank, United Nations organisations

Most of the IMAGE analyses, so far, have concentrated on the global level. For the 2015–2020 period, the aim is to learn more, in the various projects, about the key issues and ability to respond in key regions, such as Asia and Europe.

3.2 Trends in global environmental change assessment

Over time, the context for integrated assessment of the global environment has slowly changed, and in the past, the IMAGE model has responded to these changes by slowly

changing its focus. A key question, therefore, is what key trends could be relevant for the IMAGE strategy over the next 5 years. We have identified the following key trends:

1. A shift from problem identification to interest in the costs and benefits of responses.
2. Increasing interest in the governance structures in response to global environmental change problems and the role of the various actors (beyond national governments)
3. Increasing attention for the relationship between various problems (integration)
4. Renewed attention for the relationship between human development and global environmental change.
5. Increasing interest in IAM work in general, but potentially also leading to more questions about their credibility.

Below, these trends are discussed in more detail:

- For many global environmental change problems, attention seems to be shifting from the question of 'How important are these problems?' to 'What can we do to solve them?' and 'What are the pros and cons of certain response strategies?' The most prominent example in this respect is climate change. For example, the SRES scenarios and the Third Assessment Report both address the first question, whereas the RCP scenarios (2011) and the Fifth Assessment Report (2014) are much more focused on mitigation (e.g. the RCPs include both baseline and mitigation scenarios). Similar transitions can be seen in other areas (e.g. compare GEO5 and GEO3/GEO4). This clearly also means that the focus of IAM models on response strategies needs to be increased.
- Over the last few years, it has become increasingly obvious that the conflicting interests of individual countries or groups of countries reduce their ability to agree internationally on effective environmental response strategies. This trend has coincided with an increasing recognition of the role of other actors (e.g. cities, industries/economic sectors, and consumers) in responding to environmental and sustainable development problems. These trends in the governance structure for environmental problems have implications for the research topics of environmental assessments, the key clientss, and the outreach strategies.
- There is an increasing attention for the relationships between environmental problems (integration). Although integration also was highlighted in the past (e.g. the sustainable development concept was pushed in 1992), recently the interest in integration has become even more widespread. For instance, the nexus between water, energy and land, currently, forms a key research theme. There is also renewed attention for the link between climate policy and air pollution control, partly as a result of the increasingly important role of developing countries in response strategies.
- The 2012 Rio conference marked a shift from the Millennium Development Goals (MDGs) towards the Sustainable Development Goals (SDGs) that combine development and environmental objectives. This implies that there will be renewed attention for the linkages between development and environmental problems and

that integrated assessment models could be used more in support of knowledge formation.

- On European level and global levels, the interest in integrated assessment work has significantly increased, over the last 10 years. Several indications of this happening can be noted: 1) the increase in funding by the European Commission; 2) the importance of IAM work in IPCC; and 3) the emerging cooperation between IAM teams and the increasing level of professionalism. This last point, for instance, is illustrated by the emergence of the Integrated Assessment Modelling Consortium (IAMC) as an organisation that allows cooperation between IAM teams and the sharing of new insights.

4 Ambition for 2015 and beyond

Section 2 discusses a set of strengths and limitations of the IMAGE model, also compared to other IAM systems and other tools used for studying environmental problems. Section 3 describes the key focal questions for IMAGE, derived from a number of key trends that will define the future of integrated assessments of global environmental change over the next 5 years. In the past, the IMAGE modelling team has been one of the leading IAM teams. In order to maintain and strengthen the position of the IMAGE team as one of the leading IAM teams, the strategic direction and research priorities for the coming years have been identified.

One additional critical input into the strategy described here, and the further elaboration on the strategy in operational terms, described in Chapters 6 and 7, has been the advice of the Advisory Board. Therefore, Chapter 5 discusses the board's advice in greater detail and how it has influenced our strategy.

4.1 Research focus of IMAGE

Over the next 5 years, the IMAGE model will continue to be based on 2 key capabilities, as mentioned in Chapter 2: 1) A detailed, global integrated assessment model that describes key trends relevant for global environmental change in the human and earth systems by focusing on physical parameters; and 2) policy-relevant scenario analysis (simulation) and model application. These 2 capabilities will be combined with 4 key priorities for development. These priorities should be regarded as ways to prioritise decisions on new project development and model applications.

a. **Increase the focus on response strategies (R).** IMAGE should provide insights into strategies to control environmental problems for the next 40 years. The unique aspect of IMAGE is that is contains a consistent description of the physical aspects of environmental change, both in the human economy (also in relation to monetary trends) and the earth system. This makes the framework well suited to analyse the impact of individual measures and combined strategies in terms of synergies and trade-offs.
b. **Focus on feedback and linkages (I).** We will continue to build on IMAGE's ability to provide information on the linkages between various topics. Concretely, this

means that the interlinkages between the various domains must receive the same amount of attention (or more) as the improving feedback within the various sub-domains.

c. **Focus on the linkages between global environmental problems and human development (H).** As part of the IMAGE strategy, within the large range of human development issues, the focus will be on the consequences most directly related to global environmental change problems, such as access to energy, food and water, health-related consequences, and issues related to ecological services. The focus will not be on, for instance, the role of education or development strategies not related to environmental issues.

d. **Provide information on the role of uncertainty in complex environmental problems (U)**. Uncertainty plays a key role in assessment. Nevertheless, most of the IAM models (including IMAGE) have not been used in integrated uncertainty analyses for the modelling system as a whole. Developments in computing power will increasingly allow attention for this topic over the next 5 years.

These 4 priorities are in line with the Advisory Board's main advice and indicate an ambition to further develop the current IMAGE framework, in contrast to the previous period when large investments were made in rebuilding significant parts of the model (see the IMAGE 3.0 book). These priorities are elaborated further in the following sections.

4.1.1 Focus on response strategies

Clearly, the guiding questions formulated in Section 3.2 play a key role here. In general, response strategies can be described at different levels (see Box 4.1).

Box 4.1: Three levels of analysing responses strategies

Response strategies can be analysed at various levels. These include:

1) The impact of implementing certain measures (real-world changes) in terms of costs, effectiveness and side effects (increasing efficiency, improving yields).

2) The effectiveness of policy instruments to implement these measures and their associated macroeconomic impacts (e.g. use of taxes or standards)

3) The interest of various actors in response measures (options and barriers).

The IMAGE model itself is most suitable for the first level of Box 4.1 and, to some degree, the second level. In our view, the second and third levels are much more context-dependent (culture), and/or their complexity cannot be properly represented in global-scale long-term models. Still, it is possible to capture such elements in scenario assumptions and the set-up of model applications. Therefore, to address other levels related to response strategies, the IMAGE team would need to collaborate with others.

Concretely, we propose that:

- Different response measures should be introduced throughout the model, with an indication of their potential effectiveness and possible side effects. These responses preferably should be identifiable as concrete measures (e.g. specific abatement measures instead of emission factors). Still, the focus should be on the overall picture, which means that it is important to strike a balance between adding detail and transparency. At the moment, and within this context, specific areas of improvement include:
    - Better representation of land-use-based mitigation measures.
    - Better representation of strategies to respond to land scarcity; in particular yield improvement.
    - A better representation of policies directed towards land allocation on a detailed geographical grid and landscape management (including land sharing/land sparing strategies).
    - Improve heterogeneity in the human system and its implications for governance (urban/rural differences, exposure to urban air pollution).
    - Improve representation of key mitigation strategies on energy use, including energy demand and the integration of renewable energy in energy supply; better representation of air pollution.
    - Better representation of cost concepts in various parts of the model.
- In prioritisation of model improvement proposals, the list of questions under Section 3.2 will serve as a guide.
- IMAGE output should be used in studies to systematically discuss the potential consequences for governance and/or policy instruments. Findings in such projects (such as PATHWAYS) can be used for defining more realistic response strategies. This also implies the need for cooperation within and outside PBL to bring in information on policy instruments or macroeconomic consequences that are relevant for the project at hand.

4.1.2 Focus on further integration, feedback and linkages

IAMs require a good balance between complexity and transparency and integration, as well as sufficient representation of processes. In view of the key questions, our intention is to focus more on strengthening the representation of various types of feedback and linkages between the main model components. In concrete steps, this includes:

- Attention will be paid to an evaluation of the current IMAGE structure focussing on the linkages between the various sub-systems, in order to address the question of which main linkages would need further attention.
- Based on a preliminary assessment, a set of key factors has already been identified. These factors include feedback from degradation and air pollution impact on crops and vegetation, better linkages between the food, land and energy systems with

respect to residues, traditional bio-energy and energy use for agriculture, including implications of climate change for energy). Specific attention will be paid to a better representation in IMAGE of the impact of energy and land-use drivers on water extraction, and the interaction and competition between these various uses (nexus).

- Biodiversity modelling (GLOBIO) will include a wider range of impact indicators to allow a better coupling with other parts of IMAGE.

4.1.3 Focus on implications of global environmental change for human development

Global environmental change can have consequences, in terms of the changes in the environment system itself, or for biodiversity – but also in terms of the impacts on human systems. In order to analyse the impacts of various strategies, the ability of the IMAGE system to indicate human development consequences will be improved. Within the large range of human development issues, the focus will be on those most directly related to global environmental change problems; including, for instance, issues related to access to energy, food and water, health consequences of global environmental change and issues related to ecological services. The reason to focus specifically on health is that this aspect of development is linked much more strongly to various parts of IMAGE than certain other aspects. Health is partly determined by changes in environmental factors, and has socio-economic and institutional drivers that are in part similar to those of environmental problems. Effects on many ecosystem goods and services are already represented in the IMAGE framework, but we intend to improve them and make them more explicit, in terms of their relevance for human development. In concrete terms, this implies:

- Linkages to the GISMO model will be strengthened, and experiences gained in the OECD-CIRCLE project may provide useful insights for further research (e.g. that focused on health).
- The IMAGE team will further strengthen the cooperation with other teams within PBL to improve the representation of ecosystem goods and services (EGS) in the model. Possibilities to implement EGS as feedback for other IMAGE components and scenario drivers.
- Address important scarcity/competition challenges and implications for human development (e.g. competing claims on land, water scarcity). As part of this, we will follow the advice of the Advisory Board to reconsider the current linkage with the MAGNET model. Linkages between the energy and land-use systems also should be improved.
- During the 2015–2020 period, we will consider how economic development issues could be best represented in the IMAGE modelling framework. In the current framework, economic scenarios are mostly used as model input. Options, for instance, include strengthening the cooperation between the IMAGE team and economic modelling teams, improving the small economic model in FAIR, or continuing the current situation. The FAIR economic model is well suited to look at cost-benefit issues (for which it has been used in the past).

4.1.4 Uncertainty analysis

Uncertainty plays a key role in global environmental change and sustainable development processes. In principle, one of the strengths of integrated assessment models is that they can explore uncertainty associated with the consequences of linkages across various systems; among other things, because simplified descriptions can often be easily adjusted to represent the literature range. In the past, considerable attention has been paid to uncertainty in the IMAGE system, with respect to the carbon cycle and the energy system. Uncertainty also has been addressed in research articles, in the context of specific issues and processes. However, so far, no systematic assessment was done of the role of uncertainty throughout the modelling framework, except by means of contrasting, storyline-based scenarios.

In uncertainty analysis, it is important to specify for which question or research topic the insight into uncertainty is desired. Hence, in terms of the IMAGE strategy, it is important to relate uncertainty to the overall research questions formulated in Chapter 3. This means that we intend to focus the uncertainty analysis on strategies that are related to preserving biodiversity and ensuring full food security, in the context of climate policy analysis and overall assessment of sustainable development strategies. The role of uncertainty analysis will subsequently be addressed in the 'annual work programmes'.

Somewhat related to uncertainty analysis is the concept of model validation. For IAM models, that also describe the human system, model validation is not straight-forward as human systems may behave quite differently in the future than in the past. Still, there are several ways model can be evaluated including model comparison and comparison with historical trends (simply to look a similaries and differences) both in quantitative and qualitative sense. In the IAM community, there is an increasing attention to these topics and the IMAGE team will contribute to activities in this area.

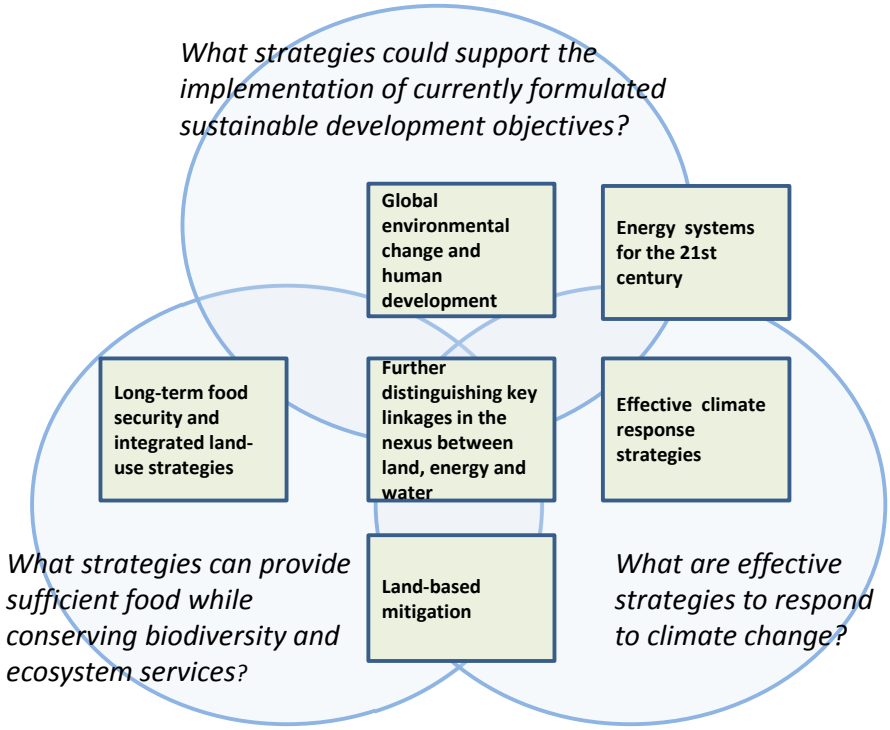
In the short-term, activities will be started in order to look at uncertainty in the land-use system and climate mitigation strategies (the latter is, among other things, related to the SSPs and ongoing DG research projects).

- The IMAGE team will set up a systematic analysis of the main uncertainties throughout the IMAGE framework. For this purpose, in 2015, a study will be done to explore the options for a more detailed uncertainty analysis.
- All annual work programmes will specifically address research initiatives on uncertainty.

4.2 Translation of strategic choices into model development strategy

The strategic choices described above need to be translated into consequences for an investment in model improvement. On the basis of interaction with the IMAGE research team, the PBL management and the Advisory Board, a set of research projects has been identified. This was done by first making inventory of possible ideas for model improvement in various areas of the model. These were subsequently prioritised and aggregated into research clusters by relating them to the key focus questions defined in Section 3.1 and to the core priorities discussed in Section 4.1. This has resulted in a total of 6 research clusters summarised here and further elaborated in more detailed activities in Annex 2.

Figure 4.1 Indication of the 6 clusters/projects and the overall scoping questions identified in Chapter 3 (see also Annex 2 for a more detailed description of potential activities)



As most modules of IMAGE are closely interlinked, any clustering of subjects will inevitably be at risk of being criticised for showing overlaps, or for showing demarcations where issues are in fact interacting. The clustering shown here was chosen in an attempt to find a balance between strengthening the linkages across the entire model (a) or in specific areas (e.g. land-based mitigation) (e), and focusing on thematic policy themes (e.g. regarding climate change, land use). Below, these clusters are explored somewhat further (the letters refer to the relationship with each of the pillars introduced in Section 4.1 (R= responses, I = integration, H= human development and U= uncertainty).

a. **Further distinguishing key linkages in the nexus between land, energy and water (R, I).** The main research question here is to identify strategies that are able to avoid any negative sustainable development consequences of expected scarcities with respect to these three key resources. As such, the project is oriented at the core priorities integration and responses. The project would mostly consist of strengthening existing linkages between the various model parts.
b. **Global environmental change and human development (R, H)**. This project focuses on the implications of environmental change for human development, with a special focus on health modelling. The core activity would be to improve the link between the existing GISMO model and the IMAGE framework. In addition, in 2015, a scoping study will be done on the linkages between IMAGE and economic modelling activities at PBL and the collaborating partners.
c. **Long-term food security and integrated land-use strategies (R, I, H)**. This project addresses the policy question of what would be needed to meet the food, fibre and fuel demand in the future while preserving biodiversity. The project focuses on increasing the ability of the IMAGE modelling framework to look into response strategies (e.g. yield improvement) in

relation to costs and benefits (e.g. in terms of the linkages with the nutrient balance). It will also look at the provisioning of ecosystem goods and services (including the role of biodiversity) and at strengthening their representation within the IMAGE model.

d. **Plausible climate response strategies (R, I).** This sub-project focuses on improving the ability of the IMAGE model to identify more realistic response strategies – as formulated also in the strategy for international climate research at PBL. This, for instance, allows to evaluate renewable energy and efficiency standards or policies regarding the emissions of specific substances (e.g. short-lived climate forcers. We will look more extensively into the role of adaptation as part of successful response strategies (which will require consideration options throughout the IMAGE model).
e. **Land-based mitigation (R, I).** This sub-project focuses on the contribution of land-use-related mitigation option and their costs and benefits. The aim is for IMAGE to provide a consistent assessment of land-based mitigation options (in the land-use, climate policy and energy systems).
f. **Energy systems for the 21st century (R, I, H).** This project focuses on the possible strategies for the development of energy systems for 21st century that would lead to a secure, affordable and sustainable supply of energy. In this context, the TIMER sub-model would be expanded with the possibility of also focusing on issues other than climate policy. The project would also increase the model's capacity to look into air pollution (including air pollution reduction strategies).

To support the achievement of further consistency in various parts of the model and the required investments in the model infrastructure in line with the advice of the Advisory Board, three other activities have been identified:

i. Scoping study on the representation of heterogeneity (R, H) in the IMAGE model. This activity responds to the increasing need to represent various societal groups in the model (e.g. urban and rural; income groups).
ii. Development and investment into data and model infrastructure
iii. Uncertainty analysis (U). This activity will focus on sensitivity and uncertainty analysis of the IMAGE framework – mostly focused at the land-use system and the IMAGE framework as a whole.

All of the activities described above will be formulated in annual research programmes, in order to achieve an implementation plan that is realistic, also in light of funding opportunities.

4.3 Areas that will receive less attention

Because the focus will be on certain areas, as indicated above, there are also areas that will receive less attention, over the coming period. Given the strong improvements made in the representation of the earth system and the detailed processes in sub-systems, the following activities will not be part of our priority strategy for the next five years:

- The resolution of the model will not be increased any further, in terms of grid cells or regions;
- Earth system processes already included in the model will not receive a more detailed representation;

- No improvements will be made to the model if these do not increase its abilities, in terms of the 4 key strategic elements listed above.
- No investments will be made in detailed impact analyses that could be done more effectively by others than the IMAGE team (e.g. that of flood risk). Here, the strategy is to increase cooperation and potentially represent results in terms of meta-relationships.
- As the focus in further development of the human development model GISMO will be on the relationships with global environmental change, i.e. human health, this implies that the attention for other topics, such as education, will be less.

4.4 Clients and users

As discussed in Chapter 2, most of the funding for IMAGE activitiescomes from: 1) institutions funding basic research; 2) international assessments; 3) government agencies with specific questions; and 4) PBL Netherlands Environmental Assessment Agency (PBL-funded projects). These groups are also expected to remain the main funders in the future. Consistent with the advice of the Advisory Board, new clients will also be considered, including organisations such as the World Business Council.

For the users of IMAGE work, information can be relevant both directly (i.e. related directly to questions of users or clients) or indirectly (e.g. via published papers that influence decision-makers or the public in general). For models such as IMAGE, the indirect information flow is at least as important as the direct one – and we will continue to prioritise this important output channel. In addition, contact with potential users of IMAGE information will be intensified, by way of the following two activities:

a) We intend to make more use of the IMAGE Advisory Board, as a means to check whether we are working in the right direction, in terms of model application and development. In accordance with the advice of the Advisory Board, we will ensure that users are sufficiently represented on the Board.
b) In 2015, we plan to discuss the details of the direction of model development and application, as indicated in this document, with a number of key clients, too.

Finally, in order to increase the relevance of IMAGE model work for existing clients and new users, the role of various societal groups in our assessments will be addressed more specifically. This can be done, for example, by cleverly designed model application, such as the sectoral approach currently used in the work for the Convention on Biological Diversity. In other cases, it will require model adoption – this is consistent with our strategy to think about how the heterogeneity of various societal groups could be addressed in the model. For instance, adding distinction between rural and urban populations allows better identification of the role of cities in addressing global environmental change issues.

5 Key findings and recommendations of the IMAGE Advisory Board, responses and follow-up

The report of the IMAGE Advisory Board (AB) has provided helpful input in the development of this document, in particular for Chapter 4 (long-term research focus), Chapter 6 (operational strategy) and Chapter 7 (collaboration and staffing). This chapter summarises the most salient recommendations by the Board and, per recommendation, provides the PBL response as well the implications for the IMAGE strategy. The AB recommendations are grouped under five headings.

It should be noted that the Advisory Board, first of all, commends the IMAGE team for the progress made in recent years, the model output and the way the model has been documented in the IMAGE book and on the website.

5.1.1 Transparency

The Advisory Board recommends to further enhance transparency by extending the website/wiki to include information on all salient model assumptions, model equations, model parameters, data and scenarios involved.

> *Response and follow-up: Further detailed and online information is desirable. In 2015 an inventory will be made of what is feasible given the available resources, starting with the online publication of as many as possible of the (key) publications that describe the model components (see Section 6.2). Support from the efforts of PBL to increase transparency in general will be sought.*

In addition, the Advisory Board recommends to develop a strategy for dealing with the increasing demand for open data and open model access.

> *Response and follow-up: IMAGE is already one of the pilots in the PBL activities on open data, and further steps will be taken as soon as a PBL-wide strategy will be implemented. Open model access seems infeasible, unless very substantial additional resources would be made available. Options for shared management and use of the model with network partners will be discussed further; see below.*

The Advisory Board also recommends to consider increasing the frequency of AB meetings, for example to once every two years (instead of the current eight year interval), for regular progress reports, and to include more representatives from the user community in the AB.

> *Response and follow-up: We intend to pursue this recommendation, this will also allow us to discuss and update ourwork on the basis of interaction with important peers and clients.*

5.1.2 General methodological aspects

It is of great importance to establish a quality assurance (QA) protocol for models and model components that are the responsibility of PBL and its partners.

> *Response and follow-up: a QA protocol will be formulated in 2015 (see Section 6.2), following from a renewed and more precise definition of the status of the various current components of the broader IMAGE framework.*

The Board recommends that the IMAGE team identifies and prioritises the major missing links between (sub)models of the IMAGE framework and decides how to act upon the findings (e.g. by including some additional links/feedback).

> *Response and follow-up: a first effort to identify missing links has already been made, and has been included in the definition of model development clusters (Section 4.2). Further elaboration of viability and implications will be done as part of the IMAGE project in 2015 and, where possible, in externally funded projects.*

The Advisory Board observes that some aspects appear more than once in different parts of the IMAGE framework. It is important that common components, such as hydrology and land use, are treated in a consistent way across all the IMAGE models and model components involved.

> *Response and follow-up: Nearly all components that drive behaviour of the IMAGE framework are common and shared, thereby ensuring consistency. Some exceptions exists for external model components; for example, the UU hydrology model PCRGLOBWB, which is used only in the impact components for flood risks and aquatic biodiversity impacts, capitalising on its specific strengths. If and when these components would become more integrated with the core IMAGE model (which is currently not the plan), the set-up will be revisited. Of the two versions of land-use allocation mechanisms, the rule-based component will be the standard for IMAGE 3.0. Where the alternative CLUMondo formulation is used, this will be clearly identified by referring to the model as: IMAGE/CLUmondo. The website will be updated to reflect this convention.*

The Board recommends that the regions currently used in IMAGE be reviewed and potentially realigned.

> *Response and follow-up: the current division into 26 regions is the result of a lengthy and careful consideration of preferences and requirements of different users of the IMAGE information, as well as of the technical aspects, such as data management and mixing grid-based and regional calculations. There seems to be no urgent need to revisit the regional breakdown, as key players in global issues and policy debates*

are already represented, and changing regions would require major data and calibration efforts.

5.1.3 Model evaluation and uncertainty

The Board recommends to extend model evaluation/validation and uncertainty analysis, with a focus not only on separate models and model components, but also on their combined use.

Response and follow-up: in the IMAGE project 2015, a further attention will be paid to assess the sensitivity and uncertainty of the different components of IMAGE and, later, the full model. Expertise and manpower from PBL's IDM sector will be indispensable to perform the work (see Chapter 4.2). With regard to model evaluation and validation, IMAGE will continue to participate in model comparison projects and contribute to activities of the scientific working group on Evaluation and Diagnostics of the IAM consortium.

5.1.4 Staffing, collaboration and funding

The Advisory Board finds the decline in permanent funding regrettable – it puts at risk sustained development, maintenance, consistency checks and data storage; especially since several groups within and outside PBL are involved. The essential resources for such core activities need to be ensured, possibly also by way of outsourcing model development to other institutes or companies. The Advisory Board thus recommends to increase the number of permanent staff to restore the balance between permanent and temporary staff.

Response and follow-up: a concerted effort will be made by the PBL sectors directly involved (KLE, WLV, NLG and DO) to ensure that more senior staff will be involved; see also Section 7.3.

The Advisory Board recommends the approach of close cooperation of PBL with a limited number of other institutes. Leadership of PBL staff at universities has helped to diversify core model development and innovation. The Advisory Board recommends the early establishment of a strategy for the development and maintenance of the entire IMAGE framework, including a division of labour between PBL and its collaborators on the models and model components of IMAGE.

Response and follow-up: A first step towards a cooperation strategy has been formulated in this strategy document (Section 7.2), which will be further elaborated together with the collaborating partners.

5.1.5 Future strategy

The Board recommends to identify new potential users of IMAGE 3.0 (policymakers, scientists, business sectors and companies), to explore their needs and to determine what IMAGE aims to do and/or achieve. This may include other European and UN institutions, and global business organisations.

Response and follow-up: in 2015, we will make contact with possible new users of IMAGE 3.0 and discuss how they could benefit from IMAGE results and insights. This may require different angles from which to present and aggregate /disaggregate results (see Section 4.4).

The Board recommends to further enhance IMAGE's potential for analysing nexus problems. The linkages between environmental challenges and their implications for broader development objectives (e.g. Sustainable Development Goals (SDGs)) are highly policy relevant, and present a good basis for research foci.

Response and follow-up: building further on early work in this field, this will be one of the cornerstones for future IMAGE work; see also Sections 3.1 and 4.2.

Future improvements and extensions of models and model components of the IMAGE framework need to be carried out in a balanced and focused way. The required major improvements in both the Human system and Earth system and their interconnections need to be identified. The IMAGE leadership needs to prioritise the many current issues for improvement and/or extension of parts of the IMAGE framework, in the light of overall IMAGE goals and limited resources.

Response and follow-up: this essentially concerns the priorities for the next 5 years. Decisions will need to be made sequentially, taking on board questions and interests of current and possibly also new users. Main clusters for model development have been identified, based on AB recommendations and internal PBL discussions (Sections 4.1 and 4.2 and Annex 2). These improvements should enhance the way the model analyses response strategies, describes key feedbacks, and focuses on human development. This holds in particular for PBL-funded projects. In some cases, improvements and/or extensions will be made in the context of and financed by external projects, or by collaborating partners for their own purposes. In each case, a deliberate decision will be taken about whether or not to adopt such new developments, weighing potential benefits for the overall goals against the efforts required.

In addition, the Advisory Board recommends that the IMAGE leadership establishes a clear strategy on ownership issues and quality assurance for models and model components that are the responsibility of PBL and its collaborating partners.

Response and follow-up: this will be taken as a starting point for reconsidering the role and place of externally developed components; see also Section 4.2.2.

The Board also recommends to consider the inclusion of low-probability–high-impact events, given their potential major impacts and policy relevance.

Response and follow-up: as a rule, a model system such as IMAGE is not well-suited to assess such events. This is therefore not a key priority in our strategy. The possibilities to simulate impacts from 'shocks' do exist within IMAGE, to a certain extent, but this requires exogenous assumptions on frequency, timing and magnitude of events.

The Board recommends to update the base year from 2005 to a more recent year.

Response and follow-up: to date, the availability of data that would allow for a complete update to 2010 has appeared insufficient, but this will be done as soon as all data become available.

Although applications should include realistic policy scenarios that reflect current policies, the development of visionary scenarios is also important.

Response and follow-up: As a rule, current policies are part of the IMAGE scenarios (e.g. on taxes, trade regulations, environmental targets). The extent to which policies and/or policy commitments are included depends on the purpose of the study. In many studies, it will be useful to distinguish 1) a 'policy free' counterfactual scenario, 2) a reference scenario – including policies (often a more plausible future) and 3) specific policy response scenarios.

Putting water higher up on the agenda as a link between human and natural systems and as a major policy domain (as important as energy and land-use policy) is desirable.

Response and follow-up: in recent years, several important steps have been taken to include water as a crucial resource, linking humans and nature. More emphasis will be put on feedbacks from water quantity and quality on human development, and on a more sustainable use of water resources.

The Board considers the GISMO model, which models human health and issues related to human development, a very important part of IMAGE, from a strategic perspective.

Response and follow-up: GISMO will be an important vehicle to include more impacts on humans, with a focus on human health (see Section 4.2). In 2015, a start will be made to further integrate the GISMO model into the IMAGE framework, with improving and expanding its coverage of health indicators, and with addressing heterogeneity.

6 Implementation of the strategy of IMAGE

6.1 Implementation of the research strategy

In the previous chapter, we discussed two important elements of the IMAGE strategy in the next 5 years. It is our intention to further translate the IMAGE strategy into concrete proposals for model improvement. Part of this will be done as part of further development of the current document. Partly, this will also occur as part of the annual planning. Although it is important to ensure the long-term strategy as part of PBL's multiannual programming, PBL's planning processes imply annual evaluations of the strategy's implication for model development, in the short term.

6.2 Operational issues

In addition to model development, several operational issues need to be addressed, over the coming years.

Quality assurance

There are several methodological aspects that need to be addressed, over the next few years. This will be done as part of the annual development programmes of the IMAGE model; mostly in collaboration with the relevant PBL department (Department of Information, Data and Methodology (IDM)). The IMAGE team, over the last years, has introduced clear standards of quality assurance for the IMAGE model. Programming guidelines have been formulated, model coupling has been formalised, and both model code and scenarios are stored in version control systems (implying that model results could be reproduced at any time). These efforts will be continued in the future. However, some key areas that require attention have been identified:

- **The linkages between the models**. IMAGE is a modelling framework. Although quality assurance systems are in place, enabling the exchange of information between the various components, considerable effort of scenario development is still being invested in the exchange of information between the various components. Further simplification of the exchange of information between the subcomponents is a priority. In addition, there are plans to develop a model version that can be coupled on a real-time basis.
- **Data quality, maintenance and consistency**. IMAGE is very data-intensive model, and these data need to be maintained, documented and updated. In addition, many parts of IMAGE rely on the same or similar data, such as on population or soil properties. Therefore, additional effort will be made that the same, most recent and best available data will be used across the various modules of IMAGE. For various

areas (e.g. land use, energy), the people responsible for data management will be identified, and a 'central point' will be established, describing the various data sources.
- **Software, programming, computing**. The recent improvements to IMAGE 3.0 have greatly increased its computing time. Therefore, model consolidation will look into ways of improving the current quality and efficiency of our software and computing facilities (grid computing).

Model documentation / transparency

Model documentation and transparency has been a key part of the IMAGE strategy in the past, as illustrated by the publication of subsequent books on the model and the release of the IMAGE 2.2 CD-ROM. The CD-ROM was also widely used by universities in communication of global environmental change issues, while the User Support System that was published on the CD-ROM became the main tool for detailed communication of model results with other research team (as well within the IMAGE team). Recently, the strategy with respect to model documentation and transparency was further implemented by the release of the new IMAGE 3.0 documentation, both as a book (hardcopy) and a wiki, and by the simultaneous release of the online data sharing portal. We will continue to invest in this. Activities in this area will be undertaken in the context of PBL strategy (which still needs to be developed).

- **Documentation.** The model documentation on the internet (wiki) will be further developed – among other things, by providing a better link to the underlying level of the key model structure and equations. Articles describing model components, such as main references, should be added to the existing wiki as well as the description of new model improvements.
- **Transparency.** The IMAGE team will pursue a policy to allow transparency in key model inputs and outputs via the online data portal and the website.

Model application versus model improvement

Experience has shown that a strong focus on model application (both in internal and external projects) may lead to a slow-down of model development. Attention needs to be paid to finding an optimal balance. In concrete terms:

- Ensure that there is a clearly separate project for model maintenance and development. Identify clear, measurable goals in this project. Ensure sufficient involvement of junior staff. This is the best guarantee that sufficient capacity is invested in model development.

External advice

The IMAGE team, in the past, contacted the IMAGE Advisory Board once every 5 to 7 years, as part of the development of a new model strategy (together with the release of a major new model version). It is now recognised that it would be helpful to contact the Advisory Board on a more regular basis (e.g. once every 1 to 2 years – in various ways, such as a telephone conference). In that context, the representation of IMAGE users and clients on the Advisory Board will be improved. The Advisory Board could help IMAGE staff not only by advising them on the direction of model development and application, but also on issues such as model quality and transparency.

7 Organisation, current situation and strategic directions

7.1 Organisation at PBL

Current situation

The IMAGE core team is housed at PBL's Department of Climate, Air and Energy. The IMAGE core team is responsible for model quality and maintenance and leads most of the activities regarding model development, documentation and outreach. At the same time, IMAGE is used also in collaboration with several other PBL teams, mostly in relation to model application (in key international projects, such as regarding biodiversity). Main collaborating PBL departments are:

- Department of Water, Agriculture and Food (WLV). Collaboration with WLV is mainly on agricultural issues. This involves WLV expertise used in IMAGE development and application, and the use of IMAGE for WLV projects (e.g. regarding food).
- Department of Nature and Rural Area (NLG). Collaboration with NLG is mostly on two key subjects: 1) biodiversity and the global biodiversity model GLOBIO, and 2) the provision of ecological goods and services. The current situation is:
    - There is a formalised linkage between the IMAGE and GLOBIO models.
    - IMAGE regularly participates in key GLOBIO projects and GLOBIO is used in key IMAGE projects.
    - NLG runs projects that intend to improve the IMAGE model for NLG-relevant issues, such as forest management and land degradation.
- Department of Sustainable Development (DO). The interaction with DO mostly concerns two issues: 1) global economic analysis of environmental change, in particular climate policy, and 2) impacts on human systems (GISMO).
- Department of Information, Data and Methodology (IDM). The interaction with IDM concerns collaboration on issues such as uncertainty analysis and access to data.

Strategic directions

In order to meet the goals and ambitions of the IMAGE strategy for 2015–2020, we need to ensure that collaborations between the core IMAGE team and other researchers are effective, efficient and properly managed. In addition, research and the analytical priorities of other teams also must be adequately addressed in development and application projects. A key basis will be formed by IMAGE team meetings. For this purpose, we will organise two types of IMAGE meetings:

- Regular project meetings to discuss and monitor concrete actions and progress (e.g. concerning land and energy representation),
- Overarching, PBL-wide meetings to ensure collaboration with the internal research teams involved and to keep strategic development on track. Close involvement in the projects and priorities of the strategic multiannual programmes of Climate and Sustainable Development and Biodiversity, Food and Development (SMJPs) is important for an adequate and timely planning of related IMAGE work.

7.2 Cooperation strategy

History and current situation

IMAGE has been collaborating with various partners, and continues to do so. At the moment, the most important partners include:

1. Utrecht University (energy system, water, nutrients, historical information). Close collaboration on model application and development with several people seconded at Utrecht University;
2. LEI (agricultural demand). Collaboration on the form of application of the MAGNET model, as part of the IMAGE scenarios;
3. Wageningen University (land-use representation and hydrology). Collaboration currently concentrates on water supply and agricultural water demand ;
4. VU University Amsterdam (land allocation). Work concentrates on the development of a land-use allocation model.
5. PIK-LPJmL. PIK's LPJmL model forms a major component of the IMAGE framework.
6. PIK/IIASA/FEEM/PBL consortium (cooperation strategy for European Commission projects). PBL has collaborated with these institutes, which have strong integrated assessment modelling programmes on funding acquisition strategies and model application projects.

Several of the partners mentioned above have expressed their interest in continuing or even strengthening the current level of collaboration.

Strategic directions

The Advisory Board has advised a continuation of the strategy of collaboration with other institutes; in particular, with key partners such as Utrecht University. In this context, in 2015, we will further develop a collaboration strategy for the 2015–2020 period, building on current network relationships. This strategy will address the following general questions:

A. *What kind of core qualities would be indispensable within the IMAGE team, in terms of size, expertise, experience and a back-up of crucial capacity?* See also Section 6.3.

B. *With whom should we collaborate? For what reasons? On which subjects? Should the collaboration be a structural one?* For the majority of these questions and issues, the current partners and fields of expertise remain relevant. For new directions, such as health impacts on humans and the role of non-governmental players in response strategies, additional partners may be considered.

C. *How to organise the collaborations?*

Here, an important question is that of how to see the interaction between PBL and its partners. In the past, PBL chose to remain at the centre and focus the collaboration mostly on specific areas. In the future, a slightly more advanced strategy could be pursued, in which partners, under certain conditions, could become more actively involved in the overall IMAGE project. This also would depend on their individual ambition levels. A more advanced strategy of transforming IMAGE into a community model, currently, seems to require too much work load given the current size of the team.

D. *Quality control in collaboration*

Independent of the level of collaboration, it is important that model improvements developed elsewhere will be subjected to adequate testing and quality control. Equally important, as also indicated by the Advisory Board, is the quality control of tools and data that have been developed or generated mainly outside PBL and used as part of the IMAGE framework (e.g. LPJmL, MAGNET and MAGICC). This should start with an inventory of the current status, followed by a further investigation of QC approaches and procedures at partner institutes. For modules that are not part of the core of the IMAGE model (e.g. some impact modules), quality aspects may play a role in determining whether they should be included in the standard IMAGE set of modules that fall under the primary responsibility of the IMAGE team, or whether they would only be used in joint projects with the collaborating institutes.

E. *Characteristics of successful collaboration*

Learning from past experience, we identified these characteristics in order to determine whether collaboration is likely to be successful. These factors should be evaluated carefully when continuing or starting collaborations:

a. Complementary expertise: complementary expertise and the resulting mutual dependency when addressing certain research and policy questions have proven to be the most important factors that determine the nature of the collaboration.
b. Benefits: Both partners should be aware of the joint and individual benefits involved in starting or continuing a collaboration: output (reports and scientific publications), resources (additional financing or PhD students/postdocs), prestige ('Model XY part of IMAGE'), and the general joy of collaborating.
c. Organisation of the collaboration (closely relates to the complementary expertise): an important success factor is to regularly hold meetings, and to have more or less equally shared responsibilities in project management, activities, and supervision of PhD students/postdocs.

For specific partners and the subjects we identify these practical implications:

1) Utrecht University: Collaboration with Utrecht University has been successful over the past few years, and encompasses a large number of issues. The intension of both parties is to further strengthen this collaboration (also in light of the recommendation of the Advisory Board) in relation to topics such as energy and climate strategies, drivers of global environmental change and interaction with earth-system research at UU (nitrogen, water and climate), understanding historical trends in global environmental change, future resource demand (also in relation to urban population) and may also involve integration activities.

2) LEI (agricultural demand): Mutual benefits need to be reconfirmed and must be strengthened via joint publications and joint funding. Close collaboration on subjects with complementary expertise (e.g. on livestock, REDD, bio-energy). Possible quality issues with MAGNET will be addressed in a scoping paper, to be published in 2015.

3) Wageningen University: Collaboration currently concentrates on water supply and agricultural water demand; possible subjects for further collaboration are crop modelling, yield gap assessment, and response strategies for agricultural systems. These possibilities will be explored further in 2015.

4) VU University Amsterdam (land allocation). Collaboration here concentrates on the development of a land-use allocation model. The possible role of CLUmondo in IMAGE will be further explored in the project LUC4C (until 2017). In the past, PBL also collaborated with the VU on wetland conversion, and the collaboration strategy may expand to again include these or other areas.

5) PIK-LPJmL: In addition to other subjects of collaboration with PIK (see below), their LPJmL model forms a core element of IMAGE 3.0. Quality control, complementary expertise, and benefits for both PBL and PIK need to be revisited and strengthened in 2015.

6) PIK/IIASA/FEEM/PBL consortium (collaboration strategy for European Commission projects). The IMAGE team has successfully collaborated with leading integrated assessment teams in Europe in projects funded by DG Research and DG Climate. It is our intension to continue this collaboration. The projects allow for further model development as well as model application and comparison.

7.3 Capacity available to PBL

Current situation

The manpower involved in IMAGE can be divided into several categories and is employed under various regimes at varying locations and is financed from various sources. The numbers presented here include all types of work on model development and applications in a variety of studies and assessments.

- **PBL permanent staff**
  This refers to people in permanent PBL employment who are involved in IMAGE projects (development, maintenance, data, application) for varying shares of their available work time. These PBL staff members are employed by the Dutch Ministry of Infrastructure and the Environment, and paid from the general PBL budget. As shown in Figure 7.1, this type of capacity, expressed in full-time-equivalents (FTE), has been declining steadily, albeit more rapidly since 2010. Note that the numbers shown in Figure 7.1 do not include work on separate impact models (GISMO, GLOBIO and GLOFRIS), but do include the policy model FAIR. It is worth noting that, in recent years, several people spent part of their time at Utrecht University.

- **Secondment at Utrecht University (UU)**
  Several members of the permanent PBL staff also hold part-time positions at UU, which strengthens the collaboration, exchange of students and staff, and the development of shared scientific knowledge related to PBL work and interests. Their

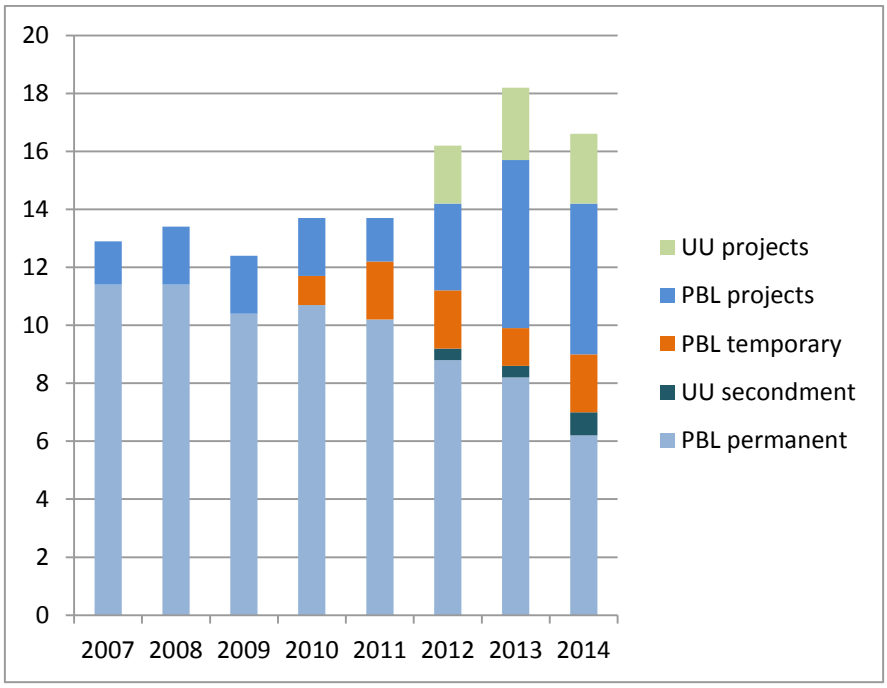
time at UU is financed partly by PBL and partly from university budgets that are allocated to strengthen integrated sustainability research.

- **PBL temporary staff**
  Depending on the sources available, PBL hires additional staff on a temporary basis. Though sometimes short in duration, these temporary contracts have proven to be valuable to complement the declining numbers of permanent staff. There is obviously a certain degree of uncertainty about the extent to which this will continue in the future.

- **PBL project staff**
  Over the last few years, increasing numbers of project workers have been hired on a temporary basis, based on external funding. Most contracts are for a term of two to four years, depending on legal restrictions on temporary employment. Hence, the mostly young graduates and postdocs involved spend an extended period of time at PBL, gaining expertise and building networks. They are financed from ear-marked project budgets, in addition to the general PBL budget, and this is an important factor in securing staff while the general budget is becoming lower as the result of government budget cuts. The majority of funds come from the EU (framework programmes, service contracts), but also from Dutch ministries (in kind support for OECD work, foreign aid support, research programmes) and others.

- **UU project staff**
  Several external EU projects involving the IMAGE framework have been undertaken by UU in recent years, with the UU serving as contractor, to strengthen the collaboration between PBL and the UU. These projects are closely related to PBL work, build on PBL experience and tools, and UU researchers were integrated into the overall research team at PBL (also on a part-time basis). The external EU projects were terminated in 2014. In addition, other funds of UU have been invested in PhDs and other positions in projects closely related to, and in collaboration with, the IMAGE team at PBL.

Figure 7.1 Capacity involved in core IMAGE work, in FTE



Overall, as Figure 7.1 shows, staff numbers have increased in recent years, but mostly in the form of temporary, project-funded team members, while the number of permanent staff has declined steadily. As the last category takes the lead in writing proposals, overseeing administrative tasks, coordinating project contributions, communicating with project partners, and training temporary staff, this implies a considerable burden on capacity and restricts the permanent, more experienced staff in making substantial contributions to research and model development.

In line with the PBL provisional strategic plan (Houtskoolschets) up to 2015, PBL supported the IMAGE work with a total of 4 to 4.5 FTEs, around 3 of which from the PBL Department of Climate, Air and Energy (KLE). Figure 7.1 shows this absorbs an increasing share of the total permanent staff. However, also here temporary staff is called upon to make up for people moving on to other work inside or outside PBL, including secondment to the UU. It is worth noting that the capacity mentioned above largely excludes development work on separate impact models, and in part that on the policy model FAIR. Some model development has also been done as part of externally funded projects, such as in research framework projects of the EU. Since 2012, a sizeable amount of time was spent on compiling, writing and publishing the IMAGE 3.0 book and Wiki documentation. Time spent in relation to tasks to comply with more formalised tool and data management, quality assurance and transparency is expected to increase further, in response to PBL-wide requirements.

In addition to manpower, the PBL IMAGE project also provides a budget for covering expenses. This includes the contracting of expertise (e.g. hydrological modelling, land-use allocation modelling, programming and code optimisation). In total, this concerns around 0.5 FTEs.

Strategic directions

The Advisory Board pays considerable attention to staffing trends related to the IMAGE team. Although the AB recognises the ability of IMAGE to attract external funding and, thus, continue to mobilise a sizeable research team, it also points to the fact that the decline in permanent staff numbers poses a risk for the quality and adequate levels of sustained development, maintenance, consistency checks and data storage, especially because of the involvement of several groups both within and outside PBL. As these are all important issues from a PBL perspective, the Advisory Board recommends that PBL expands the number of permanent staff working on IMAGE, in order to restore the balance between permanent and temporary staff.

In our view, senior researchers form an essential part of any research team, for the reasons indicated above. For a successful balance in the IMAGE team, senior capacity needs to remain within the team. It is our ambition – in line with the Advisory Board recommendation - to increase the senior staff capacity connected to the IMAGE team, if possible. At the same time, the available capacity within PBL as a whole is and will continue to be limited; therefore, adding temporary PBL staff member and those from collaborating partners remains an important aspect of staffing the IMAGE model (e.g. from Utrecht University). As the board has indicated, this should be actively encouraged as, in the past, it has helped to diversify core model development and innovation. Benefits include increased inflow of young talent, increased overall research efficiency and increased output (at reduced costs for PBL). In this context, a strategy for the development and maintenance of the entire IMAGE framework is to be formulated, including a division of labour between PBL and its collaborators on the IMAGE models and model components.

References

Carpenter SR, Pingali PL, Bennett EM and Zurek MB, (2005). Ecosystems and Human Well-being: Vol 2 Scenarios. Findings of the Scenarios Working Group, Millennium Ecosystem Assessment Island Press, Washington DC, p. 560.

CBD (2010). Global Biodiversity Outlook 3. Secretariat of the Convention on Biological Diversity.

Clarke L, Jiang K, Akimoto K, Babiker M, Blanford G, Fisher Vanden K, Hourcade J, Krey V, Kriegler E, Löschel A, McCollum D, Paltsev S, Rose SR, Shukla P, Tavoni M, Van der Zwaan B and Van Vuuren DP. (2014). Assessing Transformation Pathways, in: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, Von Stechow C, Zwickel T and Minx JC. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge (UK).

Fisher B, Nakićenović N, Alfsen K, Corfee Morlot J, De la Chesnaye F, Hourcade J-C, Jiang K, Kainuma M, La Rovere EL, Rana A, Riahi K, Richels R, Van Vuuren DP and Warren R. (2007). Issues related to mitigation in the long-term context, in: Metz B, Davidson O and Meyer L. (Eds.), Climate Change 2007: Mitigation of Climate Change. Working Group III Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report

IAASTD (2009). International Assessment of Agricultural Science and Technology for Development: Global Report. Island press, Washington, DC.

Kram T macroprudential, Neumann K, Van Den Berg M and Bakkes JA. (2012). Global integrated assessment to support EU future environment policies. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

Nakicenovic N and Swart R. (2000). Special Report on Emissions Scenarios (SRES). Cambridge University Press, Cambridge (UK).

OECD (2008). OECD Environmental Outlook to 2030. Organisation for Economic Co-operation and Development, Paris.

OECD (2012). OECD Environmental Outlook to 2050. Organisation for Economic Co-operation and Development, Paris.

PBL (2009). Growing within Limits. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

PBL (2012). Roads from Rio+20 Pathways to achieve global sustainability goals by 2050. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

Rao S, Riahi K, Stehfest E, Van Vuuren D, Cheolhung C, Den Elzen M, Isaac M and Van Vliet J. (2008). IMAGE and MESSAGE Scenarios Limiting GHG Concentration to Low Levels. IIASA, Laxenburg.

Stehfest, E., van Vuuren, D., Kram, T., Bouwman, L., Alkemade, R., Bakkenes, M., Biemans, H., Bouwman, A., den Elzen, M., Janse, J., Lucas, P., van Minnen, J., Muller, C., Prins, A. (2014), Integrated Assessment of Global Environmental Change with IMAGE 3.0. Model description and policy applications, The Hague: PBL Netherlands Environmental Assessment Agency.

UNEP (2007). Global Environment Outlook 4. United Nations Environment Programme, Nairobi.

UNEP (2012). Global Environment Outlook 5. United Nations Environment Programme, Nairobi.

Van den Berg M, Bakkes JA, Bouwman L, Jeuken M, Kram T, Neumann K, Van Vuuren DP and Wilting H. (2011). EU Resource Efficiency perspectieven op wereldschaal. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

Van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt GC, Kram T, Krey V, Lamarque JF, Masui T, Meinshausen M, Nakicenovic N, Smith SJ, Rose SK. (2011). The representative concentration pathways: An overview. Climatic Change 109, pp. 5–31.

Westhoek H, Rood T, Van den Berg M, Janse J, Nijdam D, Reudink M and Stehfest E. (2011). The Protein Puzzle – The consumption and production of meat, dairy and fish in the European Union. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

Annex 1: Process in developing this strategy document

The strategy document is meant to present a vision. It will not be a blueprint for all possible decisions made over the coming 5 years, but should help guide decisions in the right direction.

This document was developed on the basis of the following steps:

1. **Development of first draft Strategy document within IMAGE team**
    a. First draft of IMAGE strategy document (Sept 2013)
    b. Meeting with core team (October 2013)
    c. Discussions with PBL teams involved (WLV/NLG/DO/KLE)
    d. Meeting with PBL management board (June 2014)
2. **Discuss strategy with Advisory Board (July 2014)**
3. **Further elaboration (Summer/early autumn 2014)**
    a. Discussion of second draft with PBL management board (November 2014)
    b. Discussion of second draft with PBL teams involved (WLV/NLG/DO/KLE) (November 2014)
4. **Decision on IMAGE strategy**
    a. Discussion of final draft in PBL "eindseminar' meeting (March 2015)
    b. Acceptance of final draft in PBL management board (April 2015)
5. **Elaboration of strategy in subsequent multiannual programmes**

Annex 2: More detailed elaboration of the various sub-projects

Name of cluster of activities	Policy questions	Main goals	Activities	Core priorities[1]	Relationships with other project
Nexus					
Impacts on human development	What are the main factors leading to environment-related health loss? How could we reduce environment-related health loss?	Env. impacts on economic growth, welfare, well-being	• Improving GISMO linking of health component to key outputs of IMAGE (air pollution, access to water, food, energy) • 'Meta-feedback', i.e. representation of feedback on population size and economy • Scoping process in 2015: what ambitions for whole economy modelling in IMAGE?	H,I,R	OECD/CIRCLE; DGIS; GISMO; SRC/PB
Long-term food security and Integrated land-use strategies[2]	What is needed to ensure food security in 2050?	Food consumption and related health impacts	• Response strategies in Ag-Economy modelling (yield improvement by source with costs/consequences, reducing food losses, diets, etc). • Better representation of food consumption • Including undernourishment, incl. main quality aspects, health impacts	H, R	FoodSecure, DGIS/RE, PATHWAYS
	How to meet the future demand for food, fuel, water and fibre, while preserving biodiversity?	Overarching land-use dynamics with feedback on demand and intensity, accounting for multiple competing claims	• *Scoping study in 2015? Agricultural economy, role of MAGNET, possible different between short term/long term agricultural modelling* • Include timber market in land-use modelling (in MAGNET or directly in IMAGE?) • Consistent livestock system in IMAGE and MAGNET • Land use, climate change and air pollution interactions • Relationship between	I, R	

[1] Priorities identified for the IMAGE strategy:, R=Policy Responses, I=Further Integration, feedback and linkages, H=Impacts on Human Development, U=Uncertainty analysis.
[2] This activity not only addresses the specific policy question, but also develops core features of land system modelling necessary for the clusters 'Long-term food security' and ['Integrated land use'.

			nutrients and yields • Soil degradation: a) relationships between soil quality and yields; b) future soil degradation • Water: scarcity and response options/strategies;		
Plausible climate response strategies	How could greenhouse gas emissions be reduced?	Integrated assessment of various options to reduce emissions	• Better coupling between sub-models (FAIR/IMAGE/TIMER) • Better representation of various mitigation options (also see energy) • Better representation of the power sector/renewable energy • Relationships between climate change and natural emissions in IMAGE • Improve representation of non-CO_2 emissions (inertia)	I,R	Horizon2020, PATHWAYS, ADVANCE, projects for DG Clima
Land-based mitigation	How much can land-use-related options contribute to climate change mitigation? What are the side effects?	Consistent assessment of land-based mitigation options in land use, climate policy and the energy system	• More consistent bio-energy description in IMAGE (e.g. net land expansion, net emissions, food competition/price) • Representation of other land-based mitigation (REDD(+), Re-/Afforestation) (bottom-up versus top-down representation • Representation of non-CO_2 Agriculture mitigation (see also plausible climate response strategies)	I,R	LUC4C,
Energy system for the 21st century[3]	What could be the strategies for the development of energy systems in the 21st century that lead to a secure, affordable and sustainable supply of energy?	Allows evaluating other objectives for the energy sector	• More energy demand detail in TIMER on technologies and heterogeneity • Representation of issues related to energy security	R	Horizon2020
	How could we significantly reduce air pollution problems on a global	Description of process emission and air pollution levels	Air pollution: • Adopt air pollution model (FASST) • Add air pollution control costs • Couple air pollution model to MAGICC/IMAGE, FAIR, GISMO Emissions:	I, R	DGIS

[3] This activity not only addresses the specific policy question, but also develops core features of energy system modelling necessary for the clusters 'Plausible climate response strategies' and 'Emissions and air pollution'.

	scale?		• Better representation of emission reduction options and their costs		

Table 4.2: Support activities for the 2015–2020 period

Name of cluster of activities	Research questions	Main goals	Activities	Core priorities	Relationships with other projects
Consumers and interest groups/ Heterogeneity	How to best represent heterogeneity in IMAGE	Recognition of the role of urban/rural populations and 'new governance' arrangement	• *Scoping document on how to address heterogeneity consistently in IMAGE* • Consistent representation of urban/rural and income groups (heterogeneous drivers, impacts, responses)	I, H	IMAGE core
Uncertainty analysis	What is the role of uncertainty in IMAGE projections	Uncertainty and sensitivity studies	• Sensitivity analysis as a first step to prioritise uncertainties • Uncertainty analysis in land/climate component • Full, integrated uncertainty analysis related to climate response strategies	I, U	ADVANCE; IMAGE core
Infrastructure and data management	How to ensure a good linkage between various model parts	Quality control	• Further improvement of model linkages • Further improvement of model linkages and data management	I	IMAGE core

Annex 3: Brief summary of the findings of the IMAGE Advisory Board in October 2014

The Advisory Board (AB) commends the IMAGE team on the progress made in recent years, the model output and the way the model has been documented in the IMAGE book and website. In terms of its advice, the following general points are highlighted.

Issue	***Advisory Board recommendations***
Transparency	• The AB recommends further enhancement of transparency by extending the website/wiki to include information on all salient model assumptions, model equations, model parameters, data and scenarios involved. • The AB recommends the development of a strategy for dealing with the increasing demand for open data and open model access. • The AB also advises an increase in the frequency of Advisory Board meetings (e.g. once every five years, as opposed to the current eight-year interval).
General methodological aspects	• It is of great importance to establish a quality assurance protocol for the models and model components that are the responsibility of partners both within PBL and outside. • The AB recommends that the IMAGE team identifies and prioritises the major missing links between models and model components and decides how to deal with this (e.g. by including some additional links/feedback). • The AB observes that some aspects appear more than once in various parts of the IMAGE framework. It is important that common components, such as hydrology and land use, are treated in a consistent way across all IMAGE models and model components involved. • The AB recommends that the regions currently used in IMAGE be reviewed and, if necessary, re-aligned.
Model evaluation and uncertainty	• The AB recommends extending model evaluation/validation and uncertainty analysis, with focus not only on separate models and model components, but also on their combined use.
Staffing, collaboration and funding	• The AB finds the decline in permanent funding regrettable – it puts at risk sustained development, maintenance, consistency checks and data storage, especially since several groups within and outside PBL are involved. The essential resources for such core activities need to be ensured, possibly also by way of outsourcing model development to other institutes or companies.

	• The AB thus recommends an increase in the number of permanent staff to restore the balance between permanent and temporary staff. • The AB recommends the approach of secondment of PBL staff at other institutes. It has helped to diversify core model development and innovation under leadership of PBL staff at universities. The AB recommends that, as soon as possible, a strategy is established for the development and maintenance of the entire IMAGE framework including a division of labour between PBL and its collaborators on the IMAGE models and model components.
Future strategy	• The AB recommends identifying potential users of IMAGE 3.0 (policymakers, scientists, business sectors and companies), and exploring their needs and what IMAGE wants to do/achieve. The may include other European and UN agencies, and global business organisation. • The AB recommends further enhancement of IMAGE's potential for analysing nexus problems. The linkages between environmental challenges and their implications for broader development objectives (e.g. Sustainable Development Goals (SDGs)) are highly policy relevant, and present a good basis for research foci. • The IMAGE leadership needs to prioritise the currently numerous issues for improvement and/or extension of parts of the IMAGE framework, in the light of overall IMAGE goals and limited resources. • The AB recommends that the IMAGE leadership establishes a clear strategy on ownership issues and quality assurance for models and model components that are the responsibility of partners, both within and outside PBL. • Future improvements and extensions of models and model components in the IMAGE framework need to be done in a balanced and focused way. It is necessary to identify which major improvements are needed in both the human and earth systems and their interconnections. • The AB recommends considering the inclusion of low probability–high impact events, given their potentially major impacts and policy relevance. • The AB recommends updating the base year from 2005 to a more recent year. • Applications should include realistic policy scenarios, which reflect current policies, while it is also important to develop visionary scenarios. • Putting water higher on the agenda as a link between human and natural systems and as a major policy domain (as important as energy and land-use policy) is desirable. • The AB considers the GISMO model, which models human health and human development related issues, a strategically very important part of IMAGE.