Workshop on Needs for Global Nitrogen Integrated Assessment Modelling, Edinburgh, UK 5th & 6th May 2015

Background Document 3:

Issue/Compartmental Linkages: How should different compartments of the nitrogen cycle be linked when formulating global nitrogen integrated assessment models?

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1 Modeling rationale and related questions

The overall goal of INMSpp is to establish a framework for a global nitrogen model chain that enables assessment of the benefits (expressed as improved food, goods and energy production, reduced pollution and climate threats) versus the costs related to feasible improvements in global and regional nitrogen management. The benefit and costs need also to be expressed in net economic terms, despite its uncertainties. The N management system has a multi-sector approach with a strong focus on agricultural N management, but also including N (NO_x) emissions related to energy production and industrial N uses, such as nylon.

Ultimately, INMSpp aims to provide a contribution to the developing vision of the GEF/UNEP project 'Towards INMS', which explores the question of what should a global process of science support for international nitrogen policy development look like. Integrated assessment modelling of nitrogen should be seen as a key element of such a system. It should provide a resource to inform policy makers on the multiple co-benefits of improved nitrogen management, and allow examination of scenarios, incorporating cost-benefit assessment. The intended nitrogen integrated modeling approach aims to contribute to the optimization of nitrogen management in the context of food, goods and energy production and other ecosystem services at global scale. In addition, the opportunities to link to regional scale need to be considered, particularly where this can provide improved assessment supported by available datasets.

In this background document, the needed linkages between nitrogen integrated assessment modelling at global and regional scales are evaluated by discussing the following questions:

- Which models are needed in view of relevant nitrogen threats and benefits (see also background document 1)?. This also includes the aspect of scaling: which models are needed at different scales (global , regional, national, ecosystem, etc.)?.
- Which model linkages are needed to enable a consistent modeling approach?. This relates to questions like: Do we need a single integrated model approach or soft linked models (output of model 1 is input of model 2)?
- Which kind of model approaches could contribute to integrated nitrogen assessment modelling?. This refers to the need of empirical versus process based model approaches and the question which are favourable, balancing between the needed model complexity (and inherent needed data) versus available data.
- Which models are available at global scale and what is their possibility to evaluate measures needed for better nitrogen management (see also background document 2)?

Each aspect is discussed below, and this In this background document ends with a set of key questions for discussion at the workshop.

2 Needed models in view of nitrogen threats and benefits at various scales

The models to be linked for "Towards INMS" should enable assessment and quantification of the global effects of nitrogen management linked to socioeconomic factors (e.g. machinery level, technologies) and natural factors (e.g. soil conditions, water, temperature). These factors can change the consequences of N input in terms of benefits, including food, feed and fiber (wood) production and its threats, including greenhouse gas emissions (especially nitrous oxide emissions versus carbon sequestration), the quality of air, soil and water, and related human health and biodiversity impacts. Given the wide range of interactions of nitrogen cycling with other element cycles in relation to different environmental issues, such interactions require specific attention. It will e.g. be relevant to consider N, P, other macro- and micronutrients and water availability for soil quality and productivity; N and C for climate; N and S for air quality; N, P and Si for water quality. Another aspect that is relevant to consider is the aspect of regional boundaries for N, considering that all the planetary boundaries that humanity is currently surpassing (biodiversity loss, climate change, land-system change and nutrient N flows themselves) are all linked to the inefficient use of N (see also De Vries et al., 2013; Steffen et al., 2015).

2.1 Food, feed and industral production and modeling

To assess the consequences of the N management on future crop production and thus on the global food and feed system, it is important to consider the impacts of the availability of other major nutrients, i.e. phosphorus (P) and potassium (K), and water. Water availability and the associated distribution of water is essential for improved food security, particularly in reas where crop production and livestock systems are vulnerable due to physical conditions, socio-economic developments and anticipated climate change, such as Southeast Asia, Africa (North and sub-Saharan), the Amazon and Southern Europe (Foresight, 2011). A recent study in Nature (Mueller et al., 2012) shows where the current yield gaps are mainly caused by either water shortages or nutrient deficiencies. This study does not show, however, whether the deficit can be eliminated, because no comparison is made with the availability of these resources and the costs to use these resources in fields such as through irrigation. Other analyses suggest that a shortage of irrigation water in the future is likely to endanger food production, since the limit on the extraction of fresh water is almost reached (Biemans, 2012). The influence of nitrogen (nutrient) and water management on agricultural production needs modelling at global scale, distinguishing relevant subscales (watersheds/landscapes, country/regions), acknowledging the fact that many decisions leading to agricultural N pollution are actually made at the field-scale. This requires a combination of agronomic expertise on the response of crops to water and nutrients with basic knowledge of hydrology and soil chemistry. In this context, it is also relevant to acknowledge that there are currently modelling efforts being pursued that attempt to connect top-down and bottom-up approaches. This could be further emphasized by having countries develop their own methodology while sharing a set of common targets and assumptions.

Analysis of the global nitrogen cycle has shown that about 80% of harvested nitrogen from agricultural activities goes to feed livestock, with only 20% going to feed people directly (Sutton et al., 2013). This points to the critical importance of livestock as being the major consumer of agricultural products (including crops and managed grassland). Any modelling of the global nitrogen cycle therefore needs to make the link to livestock nitrogen flows, as a basis for investigating alternative scenarios (management, mitigation, consumption) that link food and feed production. Similarly, with the increasing global transition to lower use of fossil fuels, increasing amounts of agricultural (and forest) production are going to bioenergy production. These activities may have an increasing impact on the global nitrogen cycle that will need to be set into context in relation to food and feed production.

Besides, the amount of N globally traded embedded in agricultural commodities (particularly in the form of feed) has progressively increased during the last 50 years and nowadays ca. one third of the agricultural production is internationally traded (Lassaletta et al., 2014b). On the other hand, the amount of N input that it is harvested in the crops is quite different in the world nations. The evolution of this nitrogen use efficiency (NUE) has also evolved differently during the same period (Lassaletta et al., 2014a) showing how policies and better management can exert an important effect to reduce the N emission to the environment. Thus, any global N model needs to be able to evaluate the effect of global trade taking into account the regional diversity of the NUEs and yield gaps as well as to estimate the potential effect of different alternative evolution of NUEs and also of the intensification or extensification the international exchanges.

An evaluation of the effects of the changing nitrogen (nutrient) and water management on environmental quality requires various models, distinguishing spatially explicit N scenario models and global N management models to assess N (and other element) demands and needed management changes and more detailed models on hydrology, soil chemistry and crop growth. Where the N scenario N management models are more regional/global in focus, the latter are more field/ farm/ landscape focused.

N scenario models and global N management models

N use and economic development models are needed to estimate how per capita requirements of N change with economic development in relation to different management, culture, local endowment, development pathways, institutions and mitigation strategies that all influence the nitrogen cycle. These models thus predict N requirements for the production of foods and goods and N emissions in view of energy demand. This can then be compared with the current availability of N and other elements, and the extent in which the yield gap (difference between potential and actual production) in regions can be eliminated by proper agricultural management.

It is anticipated that such models should enable an:

- Assessment of food and feed demand and required crop and grass production for future changes in population growth, dietary patterns and bioenergy/biofuel production (assuming a baseline scenario and variations on it ; demand). Note: Existing scenarios may also be used but this may not allow to estimate the effect of each individual trend, because it involves various combinations thereof. Efforts should then be made to make the new scenarios as consistent as possible with existing scenarios to ensure comparability.
- Assessment of goods and energy demand and required industrial N uses from industrially fixed nitrogen and emitted NO_x for future changes in population growth and ongoing wealthy society, resulting especially in soil Nr accumulation in urban areas and urban air pollution. With economic development, the per capita industrial N use and NO_x-N emission may exceed that of food consumption (Gu et al., 2013).
- Comparison of the demand with the current crop and grass production based on the current use / presence of natural resources (current availability of water, fertility of land and supply of fertilizers, biological nitrogen fixation and fixation via NO_x, taking into account climate change (supply).
- Evaluation of the extent in which the yield gap (difference between potential and actual production) in regions could be eliminated to fulfil the demand, based on different assumptions about self-sufficiency.
- Evaluation of the possibilities to alleviate the difference in food supply and demand by changing nitrogen management, including interactions with irrigation and fertilization with other nutrients, also given the finiteness of water and phosphate resources and limited transportation options, particularly in parts of Africa and Asia.

Addressing these challenges would require detail the following types of models:

Hydrological models focusing on water availability and water balances (inputs, evapotranspiration, discharge) are needed for the characterization of the amount of water and the prediction of the effects of adapted management of groundwater and surface water resources during drought periods.

Agricultural soil quality models are needed for predictions of the change in soil quality in response to agricultural management.

Crop and grass growth models are needed to assess the response in crop and grass production (including food, feed and bioenergy) to changes in nitrogen, water and other elements.

Livestock growth models are needed to assess the needs of livestock production in relation to different management and mitigation strategies that influence the nitrogen cycle.

To provide assessments of the different components of nitrogen losses, recycling and nitrogen use efficiency, discussion is needed on which major mitigation and management options have to be considered. This is important as identification of different mitigation options (discussion of Group 2), has implications for the modelling requirements.

2.2 Environmental impacts and human health impacts and modeling.

A healthy economic planning and development requires not only an improvement of the food production but also an increase, or at least no deterioration, of ecosystem services, such as cleaner air, cleaner waters, carbon sequestration and biodiversity conservation. These require a reduction in all forms of nitrogen pollution. For example, protection of human health from particulate matter requires the reduction in emissions of nitrogen oxides (NO_x) from combustion sources and agricultural soils, and of ammonia (NH_3) from livestock management, fertilizers and biomass burning. Reduction of ammonia is also necessary because of its negative consequences for the diversity of plant species in terrestrial systems. In parallel the leaching and runoff of nitrogen (especially nitrates, NO_3) leads to eutrophication of surface waters (including coastal waters) with an associated loss of biodiversity in aquatic systems. Similarly, nitrous oxide (N_2O) emissions from agriculture and due to transport and industrial activities contribute as a powerful greenhouse gas and ozone depleting substance. Lastly, although emission of di-nitrogen (N_2) are environmentally benign, they represent a significant wastage of global energy use, and are also likely to be associated with N_2O emissions. All these effects are included in the term nitrogen cascade. Together measures that promote nitrogen use efficiency, including better recycling of all available N pools (e.g. industry, agriculture, waste water) across 'nitrogen green' economy, can be expected to contribute to more efficient production while reducing environmental pollution threats at the same time (Sutton et al., 2013).

Both the availability and quality of external N sources (fertilizer, biological nitrogen fixation, NO_x deposition) and their recirculation within the system through organic manures and crop residues)) play a central role in the assessment of their fate and effects on the environment. Combining this knowledge is essential for the development of climate-robust agricultural production with simultaneous an increased productivity and profitability and a reduced environmental footprint. An evaluation of the effects of the changing nitrogen and water management (including interactions with other elements) on environmental quality requires various models as described below.

Emission models: are needed for predictions of the change in greenhouse gas (especially N_2O and CO_2) and NH_3 and NO_x emissions from agricultural systems in response to agricultural management, as well as from biomass burning and other sources.

Air quality (atmospheric transport) models: are needed for predictions of the change in air quality, in terms of exposure (concentrations) of NH_3 and NO_x, ozone (O_3)and particulate matter ($PM_{2.5}$ and PM_{10}) and N deposition, in response to changes in NH_3 and NO_x emissions.

Human health models: in principle, exposures can be compared with critical levels and critical loads for human exposure, but a more detailed impact modeling approach could be used as well

Earth System models/Terrestrial productivity models: are needed for predictions of the change in carbon uptake and also N_2O emissions (greenhouse gas emissions) in response to N deposition, in interaction with climate and air quality of non- agricultural systems. Several ESMs arguably have the most detailed global-level vegetation dynamics of any modelling system.

Water quality models: are needed for predictions of the change in N and P concentrations in surface waters in response to N and P management. This does not only included predictions in (or at the mouth of) rivers, but also an assessment of concentrations in coastal and marine systems, implying the development of models predicting the impacts and fate of nitrogen in coastal seas.

3 Needed model linkages to enable a consistent modeling approach

Suggested model linkages to assess global scale impacts of changing N and water management on food production, greenhouse gas emissions and the quality of air, soil and water on a global scale are visualized in figure 1. Note that the figure is limited in that it does not specifically show energy emissions, nor does it currently show “Cost-benefit models”.

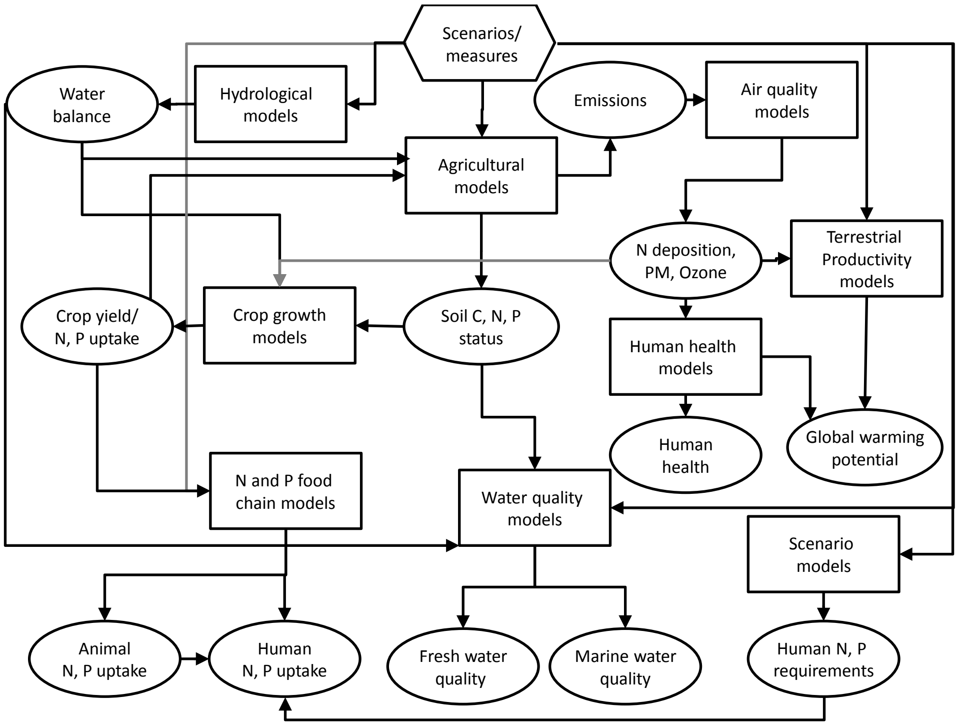

Figure 1. Suggested types of models and model linkages to assess global scale impacts of nitrogen on food production, greenhouse gas emissions and the quality of air, soil and water . Key interactions with water availability and other elements are also noted.

Regarding the agricultural sector, the N surplus, being equal to the difference between N inputs, needed for production and N harvested in the final products, is relatively easy to quantify with a reasonable reliability, but the allocation of the N surpluses to different N loss terms is much more difficult and large variations exist due to differences in climate, soil, crops, slope etc. Therefore, modelling NUE and N losses at different scales (from global scale to field scale), including the involvement of other factors that change the NUE, such as the interaction with P, K and water, should be a key issue.

In assessing a consistent modeling approach, we need to evaluate whether we need: (i) an integrated model approach or whether (ii) we can soft link models (output of model 1 is input of model 2) or is linkage not feasible/relevant. Important is not only to consider the challenge of linking models with different focal points (e.g. crop production vs. water quality), but also the fact that these models often operate at different scales. For example, most soil quality models operate at the field/catchment scale, while water quality models are more prevalent at the landscape scale. This might make option (ii) slightly trickier, but also more politically relevant given that it could potentially connect global impacts with local actions.

Another important question is how to make an explicit link to decision-making at all scales (i.e. what kind of measures are most technically/economically feasible to achieve a certain objective) – from the consumer, to the farmer, to the farmer cooperative, to the local and national government, to the international organization.

One integrated modeling approach that includes nearly all aspects at global scale is IMAGE (Integrated Model to Assess the Global Environment), being a modeling framework that started some 25 years ago as IMAGE1.0 (Rotmans, 1990), being continually updated since then, including IMAGE 2.0 (Alcamo, 1994), IMAGE 2.1 (Alcamo et al., 1998), IMAGE 2.4 (Bouwman et al., 2006) and most recently IMAGE 3.0 modeling framework (Stehfest et al., 2014). More insight in IMAGE3.0 is given in the Annex

4 Which kind of model approaches could contribute to integrated nitrogen assessment modelling.

There is a need to balance between the needed model complexity (and inherent needed data) versus available data. In general, considering the very coarse resolution of the approach, it could be argued that there is a need for relatively simple empirical approaches, based on experimental results and detailed model approaches. Conversely, whatever modelling strategy is developed, it needs to be able to assess the implications of key interactions across the nitrogen cycle, which might only be considered by more complex modes.

At the beginning of the model chain, we need a global N management model, that should be able, for a given food demand, to estimate cost-optimal production patterns, and simulates major dynamics of the agricultural sector, like trade, technological progress and land allocation according to the scarcity of suitable land, water and economic resources, being the basis for any land N management system. The economic side of the nitrogen issue also needs to be addressed here in order to balance costs and benefits (i.e. farmer and fertilizer industry profits) with societal well-being. Examples of systems that allow such predictions include MAgPIE (Model of Agricultural Production and its Impact on the Environment), IMAGE 3.0, CAPRI and GAINS global (see later)

Examples of key N impact issues that need to be addressed in the integrated modeling approach includes:

- dose response approaches for *human health*, with the dose being population density weighted Nr emissions and response being the human life year loss or the critical N level exceedances for health impacts.

- dose response approaches for *crop growth*, with the dose being N inputs and response the crop growth with response curves per crop and region accounting for the impacts of differences in water, and other element availability (Quefts approach; Janssen et al., 1990; Sattari et al., 2014).
- dose response approaches for *forest growth and related tree carbon sequestration*, with the dose being N deposition and response forest growth with response curves per tree type and region (boreal, temperate, tropical) accounting for the impacts of differences in climate and ozone exposure (EUgrow approach; De Vries and Posch, 2011).
- dose response approaches for *biodiversity*, with the dose being N deposition and response the mean species abundance or the use of critical N load exceedances for biodiversity impacts). (Globio approach; Alkemade et al., 2009).
- dose response approaches for stratospheric ozone depletion (relevant to N_2O).
- emissions factor approaches for ammonia and nitrous oxide emissions, such as the IPCC (IPCC, 2006), GAINS (Amann et al., 2011), MITERRA (Velthof *et al.*, 2007; 2009), INTEGRATOR (De Vries et al., 2011; Velthof et al., 2007; 2009) and IMAGE-N (Bouwman et al., 2013) approaches, accounting for differences in crops, soil types, climate etc.
- empirical relationships in models for *water quality*, with the dose being N and P inputs by diffuse and point sources and response the N and P concentrations in rivers, including the Global NEWS approach (Global NEWS approach; Mayorga et al., 2010), the process based IMAGE approach with spiralling concept (Beusen, 2014) and the mechanistic RIVE model (Garnier et al., 2002), now coupled to IMAGE.
- models for simulating the impact of nitrogen and phosphorus on hypoxia and harmful algal blooms in coastal marine ecosystems, ongoing activities in the GEF project "Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of Global Nutrient Cycle" (GNC project)

There are however various possible strategies for modeling. Apart from empirical approaches, based on experimental results and detailed model approaches, more detailed models may be relevant to include interactions between N, water and other nutrients or dynamic models to assess long term changes in soil element pools and availability and thereby in water quality or biodiversity in response to management.

5 Which models are available at global scale

Relevant global scale models are

- Integrated assessment (cost-benefit, and cost optimization models): GAINS (publicly available for key regions: Europe, South Asia, East Asia, while implemented for all regions globally: Amann et al., 2011) and IMAGE 3.0 (Stehfest et al., 2014) and Model of Agricultural Production and its Impact on the Environment (MAgPIE; Bodirsky et al., 2014; Lotze-Campen et al., 2008).
- N scenario models: IMAGE 3.0; Modular Applied General Equilibrium Tool (MAGNET; earlier GTAP/LEITAP; Van Meijl et al., 2006), CAPRI (Britz, 2005; Britz et al., 2005)
- Global N management models: IMAGE N (Bouwman et al., 2006), being part of IMAGE 3.0.

- Hydrological models: LPJml (Biemans, 2012), being part of IMAGE 3.0, PCR-GLOBWB (Van Beek et al., 2011) and WBM (Fekete et al., 2010).
- Crop growth models, such as WOFOST (Boogaard et al., 2013), QUEFTS based approaches (Janssen et al., 1990; Sattari et al., 2014) and SIMPLACE (Gaiser et al., 2013).
- Emission models, such as EDGAR (Van Aardenne et al., 2009; Van Aardenne, 2002), IMAGE-N (Bouwman et al., 2013), MITERRA Global, being an extension of MITERRA Europe (Velthof *et al.*, 2007; 2009) and IPCC based approaches (Syakila and Kroeze, 2011).
- Soil chemical models, such as ForestDNDC (Werner et al., 2007) or LandscapeDNDC (Haas et al., 2013), VSD+ (Posch and Reinds, 2009).
- Air quality (atmospheric transport) models: TM5 (Dentener et al., 2006).
- Earth system models/terrestrial productivity models, including process based models, such as LPJ guess (Sitch et al., 2003; Smith et al., 2014) , being part of IMAGE 3.0, CLM (Lombardozzi et al., 2013; Thornton and Zimmermann, 2007), OCN (Zaehle et al., 2011; Zaehle and Friend, 2010). and Jules (Mercado et al., 2009) and empirical response models, such as stoichiometric scaling models (De Vries et al., 2014), being an extension of response models at European scale (EUGROW; De Vries and Posch, 2011).
- Terrestrial biodiversity, with a focus on plant species diversity/abundance: GLOBIO, being part of IMAGE 3. (Alkemade et al., 2009).
- Aquatic biodiversity, species abundance: GLOBIO aquatic, part of IMAGE 3.0 (Stehfest et al., 2014).
- Water quality models: Global NEWS (Mayorga et al., 2010), being linked to IMAGE N and P output; IMAGE spiralling approach (Beusen, 2014); RIVE, being the biogeochemistry part of Riverstrahler (Garnier et al., 2002), now coupled to PCR-GLOBWB and IMAGE.

It is the global N management model at the beginning of the model chain that need to have a large capability to include and evaluate nitrogen management measures. Further in the chain the models need to be suitable to evaluate the results of such measures on environment and human health in relation to productivity scenarios for food and energy. For integrated assessment models, developing cost-benefit and cost optimization approaches is also a key issue and the question is which information is needed to supply such models. For example, the GAINS model bases its optimization on certain environmental endpoints (critical loads, human health indicators) for which further input is acquired elsewhere. This approach does not requires linked detailed impact sub-models (compare IMAGE3.0) and a discussion is needed which approach is most favourable here.

Key Questions for Discussion at the Workshop

What should be in the models?

- To what extent do the needs for food, feed, industrial N products, bioenergy, fossil energy, transport and other production and consumption pathways need to be included in integrated assessment for the nitrogen cycle?
- If we work back from the policy needs, what are the key things that nitrogen integrated assessment models need to deliver? How to consider socioeconomic factors that affect N cycling in the models and build socioeconomic pathways to reach the bright future described in different scenarios?

- To what extend do integrated assessment models of the nitrogen cycle need to consider the linkages with other element and water cycles? (C-N via climate; N-S via air pollution; N-P-Si via water; water and other limitations to improving NUE).

What are relevant model approaches, needed linkages and relevant scales

- How to deal with the scaling effects among different parts of N modelling chain?. How can IAMs take the combination of global and this local (farm-oriented) dynamics into account in a way that is helpful to decision-makers?.
- How do we define NUE in this exercise – full chain vs. crop (and what metric for crop)?. This is particularly relevant when considering different scales.
- What is the optimal balance between model complexity versus data availability?. Is there a need for relatively simple empirical approaches, based on experimental results and detailed model approaches, for a relatively fast global scale application. In how far do we need more complex approaches considering interactions between N, water and other nutrients?.
- Are there conceptual challenges in bringing together regional/global models addressing nitrogen cycling and impacts given contrasting philosophies and terminologies of different communities? (e.g. terrestrial-marine-atmospheric; biogeochemical-management-costs).
- What would be the issues and priorities in considering two concurrent short term and long term goals? i.e. Short term: to demonstrate global information flow to support integrated assessment and cost-benefit analysis (delivery within 4 years); Long-term: starting to explore the basis for a more ambitious approach and how it should look (delivery within 10 years).
- Which interfaces are needed
- How can collaboration be organized
- How can the quality of the result of modelling chains be established?

What model approaches are available that can be used?

- Which modelling areas are already well developed and can be used, as compared with modelling areas which are currently poorly developed or missing?
- What can we learn from examples where model chains have provided integrated assessment for parts of the nitrogen cycle at regional or global scales?
- What are the available component models that are available regionally and globally that can provide the building blocks for developing integrated assessment modelling for nitrogen? What are the advantages and disadvantages of different modelling strategies (e.g. process-based, empirical, level of detail etc.)?

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Annex: description of IMAGE 3.0 and it use of the shared socioeconomic pathways (SSP) storylines

IMAGE 3.0 is a comprehensive integrated modelling framework of interacting human and natural systems, addressing a set of interlinked global environmental issues, including climate change, land-use change, biodiversity loss, modified nutrient cycles, and water scarcity (see Figure 2).

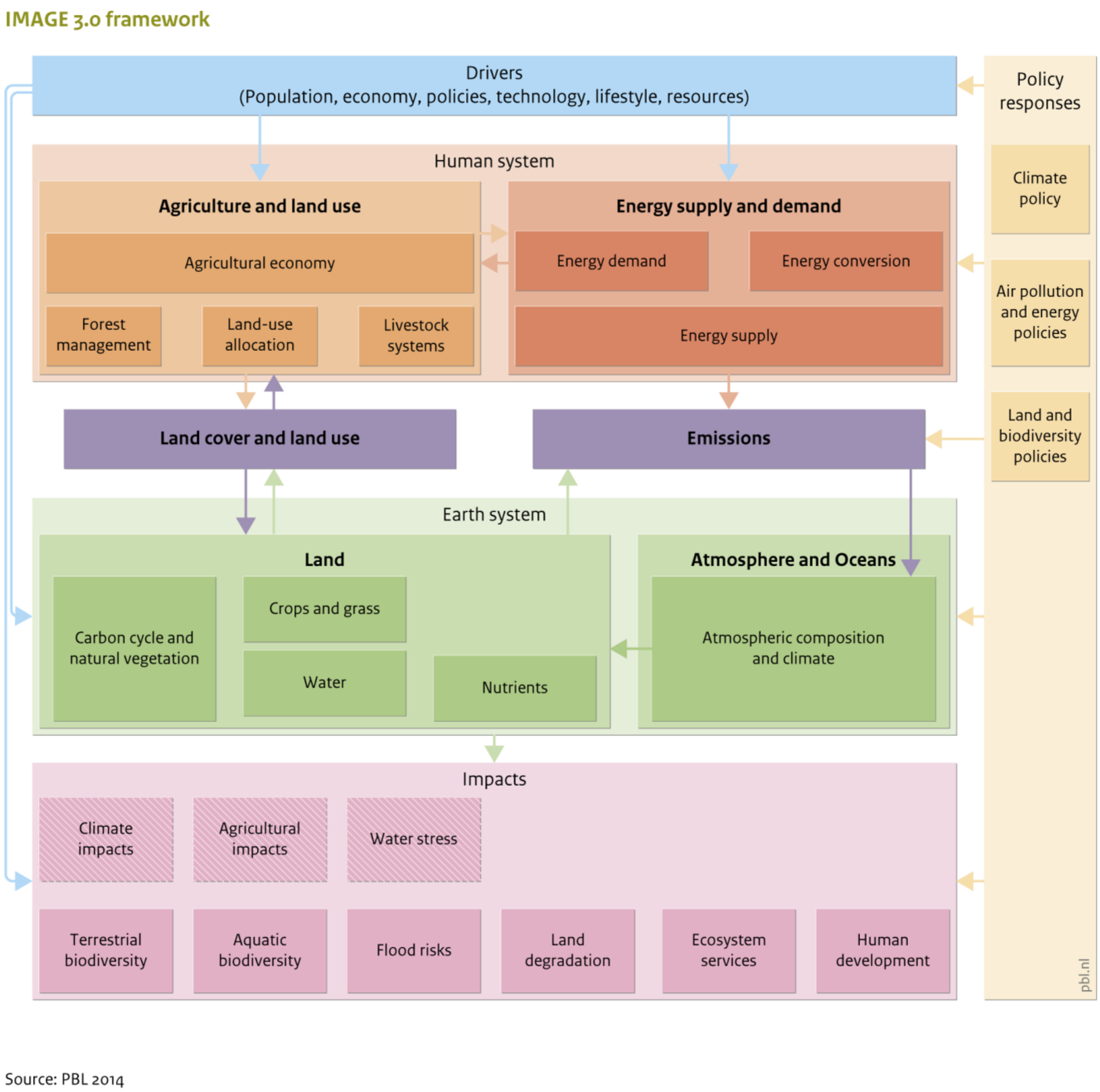

Figure 2: The IMAGE3.0 modeling framework. The Dark-coloured boxes refer to model components. Impacts are calculated in model components shown in the lower box.

The model framework is suitable for global long-term (up to the year 2100) assessments of interactions between human development and the natural environment, and integrates a range of sectors, ecosystems and indicators. The model identifies socio-economic pathways, and projects the implications for energy, land, water and other natural resources, subject to resource availability and quality. The resulting emissions to air, water and soil, climatic change, and depletion and degradation of remaining stocks (fossil fuels, forests), are calculated and taken into account in future projections. The IMAGE framework is spatially explicit (30 by 30 minutes or 5 by 5 minutes), and covers a broad range of closely interlinked aspects including water availability and water quality, air quality, terrestrial and aquatic biodiversity, resource depletion, with competing claims on land and many ecosystem services, all aspects also being part of the integrated N model framework. Implementations for nutrients (nitrogen) are still ongoing.

Global carbon and nutrient cycling in the coming century will strongly depend on global (economic) development. IMAGE3.0 is one of the core models of the Shared Socioeconomic Pathways project and has implemented the five shared socioeconomic pathways (SSP) storylines (Kriegler et al., 2014). This are the most recent set of scenarios developed for IPCC used to study the impact of future global change (climate change, land use changes and water use on hydrology, flooding risk). The included SSP scenarios are: a sustainability scenario (SSP1) in which we make good progress toward sustainability, with ongoing efforts to achieve development goals while reducing resource intensity and fossil fuel dependency. A middle of the road pathway (SSP2) or business-as-usual world, a fragmented world with regions differing widely in economic development (SSP3), a scenario with a high unequal world in which a relatively small, rich global elite is responsible for most of the greenhouse gas emissions, while a larger, poor group that is vulnerable to the impact of climate changes, contributes little to the harmful emissions (SSP4) and SSP5 involving traditional development with a focus on economic growth with continued high greenhouse gas emissions.

These scenarios need to be expanded with quantitative scenarios for air and water pollution. INMS can also play a role in the construction of scenarios for nutrient management, including fertilizer use efficiency, linking livestock and crop production through the closer integration of nutrients from manure, emission reductions, etc.

Considering the above, the IMAGE3.0 modeling framework could be a good candidate to play a pivotal role in INMS. However, it is also necessary to investigate what additional model approaches still have to be used in in the calculations and what linkages can be made to other model approaches in terms of soft linking of models . The advantage of this approach is that there is already a strong consistency in the modeling approach due to its integrated character (see also section 5).