NPDA postdoc programme 2009

The Integrating Global and LOcal assessment models (IGLO) project

1. Rationale

Local environmental problems and dynamics of socio-environmental systems are often connected to global level changes that either drive or constrain local processes. Biophysical processes within the climate and water system operate across multiple scales and cannot be adequately studied at regional to local scales without explicitly addressing global level feedbacks and teleconnections. Globalization of the economic system and global scale socio-cultural exchanges through trade and migration have resulted in a multiple interactions and feedbacks between local and global developments. At short time scales it is sometimes possible to assume global level influences to be exogenous to the system under study. However, when looking at longer time scales and integrated systems it is necessary to look at global level processes from a more dynamic perspective, both as driver of regional and local dynamics and as a result of the aggregate effect of local and regional processes. Including both top-down and bottom-up interactions between regional and global scale processes is therefore essential in better understanding socio-environmental systems.

The development of integrated assessment models can be seen as a response to the need to integrate knowledge of interacting systems across different scales. In the 1980s and 1990s a number of different integrated assessment models were developed (e.g. Alcamo et al., 1998; Alcamo et al., 1990; Warren et al., 2008; Prentice et al., 1993). Within most integrated assessment models land use is a central component. Land use is the result of human decision making in response to (global) markets of food, fuel, wood and fibers and more than 75% of Earth's ice-free land shows evidence of alteration as result of human residence and land use (Ellis and Ramankutty, 2008; Foley et al., 2005). In turn, land use and land-use change drives many environmental processes, e.g. the water cycle, greenhouse gas emissions, biodiversity etc. Land use is therefore both a cause and consequence of many socio-environmental processes leading to Earth system dynamics. The variety of forces that drive change in the use of land are extensive and complex, including spatial planning policies designed at local, regional, national and supra-national levels (Lambin and Geist, 2006). As a consequence of this complexity the understandings obtained at the level of individual case studies of land change have often not been incorporated in integrative assessment methods at regional to global scales.

Because land use is central to global environmental change many mitigation and adaptation options are directly or indirectly related to the spatial planning of land use. The recent discussion on policies with respect to the cultivation of biofuel crops is largely related to the indirect effects on land-use change, both locally as well as through tradeoffs in other world regions (Banse et al., 2008; Kline et al., 2008). Although the role of land change in earth system processes is often obvious, many processes are difficult to quantify and highly uncertain due to intricate feedbacks across multiple temporal and spatial scales leading to policy debates that can only sparsely be informed by solid scientific information. Currently, much research effort focuses on the modelling of the complex interrelations between changes in land use and climate. The relationship between the two is interdependent: land-use changes may impact the climate whilst climatic change will also influence opportunities for future land use (Dale, 1997; Watson et al., 2000). The former feedback is a biophysical process, the latter will mainly be steered through policy and (land-use) planning, posing interesting challenges for researchers and planners (Kabat et al., 2005). The feedbacks of land-use change on the climate are typically modelled in global change models such as IMAGE (Alcamo et al., 1998; Eickhout et al., 2007), whereas the impact of climate change on local land-use patterns is mostly the domain of smaller scale spatially explicit models of land-use change (Koomen et al., 2007; Parker et al., 2003; Verburg et al., 2004). The latter approach integrates sector-specific demands (for housing, agriculture, etc.) and land suitability for certain uses and provides an indication of the likely use at a specific location in the future under different climate conditions.

Current practice in modelling approaches to land-use change has several limitations. Most notably these are:

- separate assessment methods are used at different scales. Some methods exist for constraining local models by global models, but consistent connections and bottom-up feedbacks are generally missing (Heisterman et al., 2006; Verburg, 2006).
- land-use change is explained from a specific disciplinary focus often related to a single dominant driver of change (e.g. economics-based land market perspective, transport perspective or a deterministic agricultural perspective based on land suitability). Combining the strengths of the available concepts, approaches and techniques instead of elaborating on the approach belonging to the modeller's own discipline is regarded as one of the most important tasks

for future research (Verburg et al., 2004).

This proposal aims to consistently address the integration of processes operating across different scales and enhance the linkages and feedback between socio-economic processes and biophysical processes within the land change system. Modelling will be used as a central tool to address these issues resulting in improved concepts and methods for integrated assessment. The (conceptual) models and methods will be implemented in, respectively, an existing global integrated assessment model (IMAGE) and a newly developed local land change modelling framework (CLUE-scanner) that builds on two successful existing modelling frameworks CLUE (Verburg et al., 2002) and Land Use Scanner (Hilferink and Rietveld, 1999).

2. Objectives and anticipated results

The project has the following objectives:

1. Improved insight and conceptual models on linking land-use change processes across different scales;
2. Improved insight and conceptual models for addressing feedbacks and interactions between economic and biophysical processes in land use;
3. Implementation of conceptual models in consistent operational land-use modelling frameworks (through new modules and consistent linkage of existing models) to be used in assessments of climate change and ex-ante evaluation of policies.

The anticipated results of the project include:

4. Scientific understandings published in five scientific papers in peer-reviewed journals; editing of a special issue/section of a journal;
5. Contribution to the scientific discussion in this field through an international workshop and special session/symposium during an international conference;
6. Enhanced collaboration between research groups from different disciplines/universities;
7. An integrated, operational modeling system based on linked models for application within ex-ante and scenario studies. Such applications can take place in the context of the Dutch Knowledge for Climate (KfC) research programme project and other international initiatives. The modeling system will especially help to provide explicit insights in the role of feedbacks and interactions between biophysical and socio-economic processes addressed in the context of the applications.

3. Organisation of the project

The overall project includes two postdoc positions that will cover the larger part of the proposed research. The two post-docs are intended to interactively work together on the overall concepts and framework in order to arrive at consistently linked models. However, each of the post-doc projects has its own focus. Post-doc 1 will focus on the linkage of global scale integrative assessment models to land-use modeling and regional assessments while post-doc 2 will focus at the linkages and feedbacks between socio-economic processes and biophysical processes influencing land change at local scales. Together the two projects will allow a consistent, multi-scale framework for analysis without attempting to merge everything within one (hard to manage) single model. Figure 1 indicates the overall organization of the project. Three overall themes are identified that address the main linkages between the individual projects. These themes, including the communication and dissemination, are jointly addressed by the postdocs.

Theme A: Feedbacks between scales: top-down and bottom-up processes.

Within this theme a consistent and flexible coupling of global scale analysis of land change and regional level analysis has to be ensured. This coupling should not only relate to a downscaling of global scale processes to regional analysis as common in current multi-model frameworks (Verburg et al., 2008) but also explicitly address how regional and local responses (such as adaptation to climate change through spatial planning) feed back to global level responses or tradeoffs for other regions. During the first months the overall interactions and concepts to frame the individual models and interactions will be defined. During the implementation this will be regularly revised.

Theme B: Interaction between socio-economic and biophysical processes

Any truly integrated model of land-use change should be able to capture both socio-economic processes related to, for example, urbanisation and agricultural developments and biophysical processes related to, for example, increased flooding frequencies due to climate change, regrowth of vegetation on abandoned farmland or environmental degradation. The challenge here is that these processes typically follow a different logic and happen at different spatial and temporal scales. Both proposed research projects will need to tackle a better incorporation of the interaction between socio-economic and biophysical processes. However, given the different scales of analysis, the solutions and applied methodologies will be different. Postdoc 1 (global scale) will use land-use systems instead of land cover types as basis for the model development as an improved representation of the interaction of socio-economic and biophysical processes. Postdoc 2 (local scale) will explicitly include time-lags and different levels of feedback between socio-economic and biophysical processes in the model structure based on an extension of traditional modelling concepts. The different disciplinary backgrounds of the members of the research group will allow a constructive discussion aiming at innovative solutions to address these interactions.

Theme C: Application: scenario and trade off analysis

In close collaboration with the relevant projects within the Knowledge for Climate (KfC) programme one or two scenarios will be selected that will be simulated and analyzed with the interlinked models to test and analyze the interlinked models and concepts. Trade-offs between impacts, scenarios and local vs. global effects will be analyzed with specific attention for the role of feedbacks in the modelling results. Further application of the modelling framework will be done in the context of the KfC research programme.

Communication and dissemination: workshop and special session at an international conference

To consolidate the inputs of other research groups within the project a mid-term workshop will be organized on '*Integrated land-use modeling: from global to local'* where a number of key researchers in this field will be invited to discuss the proposed modeling approaches in the project. This will allow the exchange of ideas with the possibility to still use these ideas and comments within the proposed research. At the same time the workshop aims to identify challenges, build stronger collaborations and focus the work on innovative aspects (and avoid repeating work done at other institutes). The 2-day workshop will feature targeted presentations by the participants with long working sessions to discuss innovative concepts for modeling land use. Approximately 25 participants are foreseen with approximately 10 invited guests and a selection of applications through an open call announced through the Global Land Project (IHDP/IGBP) and other relevant networks. At the end of the project results will be presented as part of a special session or symposium organized within the context of an international conference relevant to the research theme (e.g. IHDP open meeting, GLP conference, IALE symposium, AAG meeting). Such organization will potentially attract a wide audience without large logistic requirements. It is envisioned that the speakers of the special session/symposium are invited to contribute to a special issue of a peer-reviewed journal to be edited by the senior researchers involved in this project.

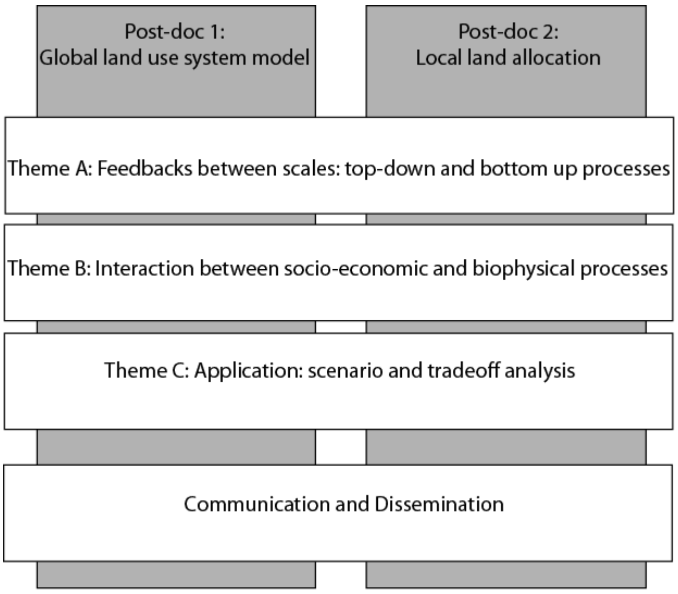

Figure 1. *Organization of the project indicating the two post-doc projects and overall themes addressed.*

4. Postdoc 1: Global land-use system model

4.1 Problem identification and objective

In spite of the very central role of land use in integrated assessment at continental to global scales the representation and simulation of land-use dynamics is often insufficient due to:

- lack of spatial and temporal accuracy: spatial resolution is, in many models, limited to world regions or 0.5x0.5 degree (~50x50 km) pixels that represent land use by one dominant land cover type that is supposed to cover the entire pixel
- a representation of land use mostly by land cover (i.e., forest, agricultural land, grassland etc.) rather than by the actual land use which also includes management aspects important to Earth system processes (i.e. grazing land vs. natural grassland).

The underlying hypothesis of the proposed research is that integrated assessment modelling can benefit from using land-use change as an integrative platform of human and environmental processes by multi-scale analysis: land use is the aggregate result of individual land-use decisions while, at the same time, the cause of global level change in amongst others the climate system. For this postdoc project the specific objective is to create a new, innovative, method for land-use modelling at global scale based on a high-resolution representation (approx 5 min resolution, or ~10x10 km of land-use systems). This conceptual model should potentially benefit multiple integrated assessment models (Lotze-Campen et al., 2008; Warren et al., 2008) and will be tested by implementation in the IMAGE model (Bouwman et al., 2006) to operationalize the concepts and link the results dynamically to postdoc project 2.

4.2 Methodology

a. Land system characterization

A land-use systems classification will be made as a basis for modeling. Land-use systems are representing both aspects of land cover (e.g. farmland vs forest) as well as land management (e.g. grazing vs. fodder production). At the inherent coarse scale of analysis at global level, land-use systems are able to represent mosaic landscapes represented by a mixture of different land uses as single systems which acknowledges the importance of such landscapes worldwide. In representations based on the dominant land cover such landscapes are not correctly represented. A number of recent papers have used a land-use system representation at regional level (Van de Steeg et al.) and global level (Ellis and Ramankutty, 2008) to represent spatial variation in land use. The latter defined 18 different so-called anthropogenic biomes or 'anthromes' at the global level, which represent globally significant patterns of direct human interaction with ecosystems. Each of these biomes shares a common level of interactions between humans and the environment; examples include ‘dense settlements’, ‘pastoral villages’ and ‘populated rainfed croplands’. Each of these biomes consists of a heterogeneous landscape mosaic combining a variety of different land covers. Human-environment interactions lead to different mosaics due to natural variation in terrain, human enhancement of the natural heterogeneity by concentrating activities at the most productive locations and heterogeneity caused directly by the specific activity types of the considered biome.

Instead of modeling dynamics between different land cover types the change in land-use system (or anthrome) will be simulated in the model. Such changes can either or both consist of a change in management and land-use intensity or consist of a change in land cover (e.g. the change from an ‘intensive arable production system’ to a ‘peri-urban land use’) The 18 classes of the anthropogenic biome map are, however, not always fit for simulation purposes and a linkage with macro-economic models. Therefore, based on the current ‘anthromes’ map and other global data a global land-use system map will be derived that is suited for land-use simulations.

b. Conceptual model development

The conceptual model development will be based on the current state-of-the-art in land-use modeling, linking theory and observations. Core elements of the model development will be the selection and quantification of driving factors (proximate causes) of land change, the definition of land change trajectories (e.g. natural succession and typical land-use system conversion matrices) and the interactions with economic sector models. Theoretical considerations (e.g., Walker, 2004; Turner et al., 2007), meta-analysis of case studies (Geist and Lambin, 2002, 2004; Keys and McConnell, 2005) and global/regional level statistical analysis will be used to identify relations between driving factors and the location/change in land-use systems. Specific attention will be given to factors that are dynamic in time and endogenous to many integrated assessment models or multi-model systems such as population, climate, accessibility and market influence. The most recent developments in global datasets will be used in the analysis, e.g. the irrigation map by Siebert and Döll; crop distribution by Monfreda et al., (2008) and accessibility by JRC-IES.

It is hypothesized that land-use system change can both occur as a consequence of a change in the local conditions at a location (e.g. climate change, demographic changes) as well as through the increased demand for one or more of the commodities produced by the land-use system. The location of change also depends on the local conditions, conversion costs and land-use history. Demand and supply of food, fuel, fiber and wood are both a driver and a result of land-use system change. Macro-economic modeling approaches (Banse et al., 2008; Lotze-Campen et al., 2008; Meijl et al., 2006; www.gtap.org) are frequently used as part of integrated assessment models to address the role of markets and (sector) policies as determinant of supply/demand relations for different sectors. Land supply curves are incorporated in these coarse scale models to capture the marginal productivity of different land areas and spatial variability (Heisterman et al., 2006; Meijl et al., 2006). At the moment these functions are largely static. A more dynamic approach that enables accounting for the land-use system dynamics as well as for spatial policies targeted at specific areas (e.g. nature protection or REDD agreements) is foreseen, thus accounting for bottom-up impacts on the global economic assessments and providing a consistent linkage with the land-use system model foreseen in this proposal (this issue will be elaborated in close collaboration with postdoc project 2).

Frequent communications with the developers of macro-economic models are foreseen to ensure a straightforward implementation of the relation between the supply/demand simulation and the land-use simulations. This interaction will be based on existing collaborations within other projects at European scale which have established a good multi-disciplinary platform for exchange.

c. Implementation in global land-use system model

The IMAGE model is an ecological-environmental modeling framework that simulates the environmental consequences of human activities worldwide. The IMAGE model was used for, among others, the IPCC SRES analysis, the United Nations Environment Programme’s Global Environmental Outlook 3 and 4, and the Millennium

Ecosystem Assessment. The conceptual land-use system model developed in the proposed project will be implemented within the framework of IMAGE. Macro-economic dynamics are captured by a dynamic coupling (multi-model approach) to the GTAP model following the existing linkages between GTAP and IMAGE (Eickhout et al., 2007; Meijl et al., 2006; Verburg et al., 2008).

The current land allocation module of IMAGE only accounts for land change processes in a simple way using a small number of generalized driving factors, a representation of land use by the dominant land cover within 0.5 degree (~50x50km) pixels (and a number of crop types) and a homogeneous management factor representing land-use intensity across large world regions. Embedding the new land-use model within the IMAGE integrated assessment model will make use of all existing parts of the IMAGE model framework, using the demographic (PHOENIX), macro-economic (GTAP) and climate model linkages as well as the environmental assessment models on greenhouse gases, energy and biodiversity (GLOBIO3) in a consistent way to drive and respond to the land-use model. It is expected that the new land-use system approach will strongly improve the land-use projections in all applications of the integrated assessment model. And, more important in this context, it will ensure that the land-use system model itself will take into account all direct interactions with its driving factors and responses.

d. Uncertainty assessment

Uncertainty is inherent to modeling complex systems due to the limited data availability, the difficulty to capture human decision making, and the large temporal and spatial variation in processes. Specific attention will be paid to uncertainty and errors that may evolve from the coupling of model components originating from different disciplines, and those that are a consequence of up-scaling and down-scaling procedures (e.g., ecological fallacy; Easterling, 1997). A full uncertainty analysis of all types of uncertainty is not feasible within the time frame of the proposed project. However, careful documentation (following 'good modeling practice guidelines') of all possible sources of uncertainty will make an uncertainty analysis as part of the regular evaluations of the IMAGE model possible.

5. Postdoc 2: Local land allocation

5.1 Problem identification and objective

The research of postdoc 1 will improve the representation of land use at the global scale. Inherent to the scale of analysis, the representation is still highly aggregated (with a spatial resolution approximately 10x10 km) and the processes of land change are highly generalized given the global scope. For local and regional scale assessments the global scale simulation results can provide a context, but they need to be elaborated based on the region-specific conditions, to make an assessment relevant to regional policy and spatial planning possible. At the same time, local specifications are needed to constrain large scale processes.

Local land-use changes are driven by both socio-economic processes and biophysical processes that typically follow a different logic and happen at a different time scale (for example due to process-specific time lags). Economic processes are, to a large extent, explained by profit maximizing behaviour and happen on a long time scale, whereas physical processes are generally well captured with spatially explicit simulation rules using short intervals . In fact, these different processes are generally simulated with different methods. Spatial interaction and discrete choice based approaches are generally used to simulate equilibrium conditions for economic processes, while rule-based and cellular automata based dynamic simulation is used to mimic physical processes. Application of the latter approach to economic processes may lead to sub-optimal results. Obviously similar problems will occur when an economic approach is applied to physical processes.

Both approaches, usually also have a different time resolution, that each has its own advantages. Short time intervals (e.g. one year) capture the processes of change and the state of dynamic variables that are relevant for modelling natural processes such as succession, erosion and carbon sequestration. A lower time resolution (e.g. ten-year steps) allows market prices to be estimated better due to sufficient demand and supply of land. An appropriate specification of market behaviour and optimizations is relevant for modelling different types of urbanisation and other human processes that take a larger time span and larger spatial environment into account.

The main objective of this postdoc project is to develop an integrated approach that incorporates both socio-economic and biophysical processes at the local scale in land-use modelling and feed the results back into the global model of project 1. A crucial issue here is to come to a unified dynamic assessment framework for land suitability that incorporates the local potential for different types of use (urban, agricultural and natural) based on, for example, market preferences, land-use related adaptation measures and biophysical conditions that change over time. In addition, the approach should be able to express changes within short periods (preferably on a year-by-year basis) to accommodate biophysical and path-dependent processes.

Innovative aspects in this postdoc project include:

- the introduction of an economic rationale in overall suitability definition to allow for open competition of rural and urban land uses (e.g. account for increased competitive performance when forests mature);
- the introduction of dynamics in the allocation of urban land uses (e.g. yearly time steps for specifying demand, calculating suitability and allocating land use).

5.2 Methodology

a) Conceptualising the land suitability framework

To conceptualise land suitability a monetary (utility based) framework is proposed following the rationale of many existing land-use models. Suitability for a particular type of land use is thus defined as the net benefits for that use, in line with bid-rent theory and the host of literature on land markets and land evaluation. A utility-based approach is selected because it allows for a unified assessment of land suitability that can be directly linked to human behaviour and can, potentially, be defined in a relatively objective way. It will provide a common reference scale for the definition of suitability that allows for straightforward interpretation, direct comparison between different types of land use and regions, and a framework for the inclusion of future changes in location characteristics. It thus offers the possibility to insert discontinuities or anticipated scenario-based changes (Overmars et al., 2007), that are particularly relevant in the context of, for example, climate change. These advantages are lacking in alternative approaches such as pure statistical techniques, multi-criteria analysis or the analytical hierarchy process.

Utility-based approaches are commonly applied to add behavioural logic to land-use models, but this is normally confined to the modelling of a single land conversion process (urbanisation, deforestation) that is steered by economic logic. Typical examples include the well-known spatially explicit economic models for deforestation (Chomitz and Gray, 1996) and urbanisation (Irwin and Geoghegan, 2001) and more recent micro-simulation or multi-agent model that apply utility functions to steer location choice of various urban actors (e.g. Waddell et al., 2003). A major challenge for the proposed monetary framework lies in providing a dynamic definition of the profitability of a location while accounting for issues such as long-term investment strategies, depreciation and changing neighbourhood conditions. The introduction of dynamics to the economic rationale of, for example, urbanisation processes is still in its infancy, as is discussed by (Irwin et al., 2009). Another major challenge lies in including natural types of land use into the conceptual framework. This will be pursued, however, to include such land-use types in the competition for space and be able to pinpoint the locations where, for example new nature will arise as a consequence of policy interventions (that can either be considered as financial incentives or taxes) or the lack of agricultural interest (where production costs exceed expected benefits).

b) Applying the conceptual framework

The proposed suitability framework will be applied to a limited number case study areas that will be selected in close cooperation with the other postdoc. Application is foreseen in areas where economic and biophysical processes interact and that are relevant to the Knowledge for Climate research programme. Interesting case study areas may relate to feedback processes such as:

- climatic changes causing higher flooding frequencies that lead to increased flood risks (as expressed in damage or casualties) resulting in higher land prices that eventually steer changes in urbanization patterns;
- vegetation succession on abandoned farm land that impacts nature policies that in turn may affect conversion costs/land price;
- land degradation processes that influence land values and investment potentials and thus exacerbate degradation processes.

Suitability values for different types of land use for the selected areas will be primarily inferred from economic analysis (revealing the investment behaviour of developers and farmers) through the inclusion of hedonic pricing analysis of land values. Currently available micro-level data offer interesting opportunities to link bid-prices for different types of land to spatially explicit land-use models (Ph.D. theses at VU). This analysis provides spatially explicit land-value maps for a range of land-use types. Additional spatially-explicit information on land suitability from relevant case- studies will then be used to incorporate reference to processes that cannot be directly obtained from the hedonic pricing analysis (e.g. farm abandonment). Explicit attention will, furthermore, be paid to the inclusion of biophysical conditions and the impact of biophysical processes such as vegetation succession (e.g. increasing the value for timber production or carbon stocks) or land degradation (limiting the value for agriculture) in the land suitability framework.

c) Implementation in local land change model

The insights gained in the previous two phases will then be implemented in an operational model of local land change: the recently developed CLUE-Scanner environment. This environment is a combination of the well-known CLUE model and the Land Use Scanner. The model is particularly useful as it is able to cover a complete range of urban and rural land-use types and places the suitability for different land-use types central in the modelling process. The modelling environment can, furthermore, be used in a multi-scale setup and, for example, be linked to the IMAGE model. The harmonisation and interrelation of the two models will be performed in close cooperation with the other postdoc. Model simulation will be performed for the selected regions and aims to test whether the feedback processes considered to be relevant in these areas (e.g. flood risk on urbanisation) can indeed be modelled. Through a careful selection of case study region and future scenario the simulations will, furthermore, provide useful input to the Knowledge for Climate research programme.

d) Validation

To assess the merits of the proposed monetary suitability framework resulting simulations will be compared with model runs that are based on statistically inferred suitability definitions. These validation runs will be performed on a period for which actual land-use observations exist. Common pixel based map-comparison methods at several resolution will be applied to assess the degree of correspondence of the simulated land-use patterns with observed patterns (similar to the work of: Pontius Jr. et al., 2008).