Advancing the Representation of Human Dimensions in Large-scale Land Use Models

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Chapter 1 | Introduction

1.1 Background

The collective impact of human activity on the earth system has accelerated steeply since the 1950s (Steffen et al., 2015). Humanity's resource use already exceeded three out of nine planetary boundaries including greenhouse gas concentration, nitrogen use, and biodiversity loss (Rockström et al., 2009). It is uncertain to what extent this will harm the major ecosystems or even let them reach tipping points and collapse. Such system dynamics on the global scale would have severe consequences because the functioning of ecosystems is the basis for human life. Yet, most people wish to continue or develop a lifestyle, which (unintentionally) demands more resources. Individuals and organizations who wish to reverse this trend are confronted with the inertia and lock-in of social, technological and political systems that stimulate further exploitation of natural resources (Scheffer, 2009). Many efforts were undertaken by the global political and scientific community to assess global environmental change and the potential cost of inaction was indicated (e.g. IPCC and IPBES). But after decades of knowing about the dilemma, the situation is far from being under control (Ripple et al., 2017).

Within global environmental change, land use change holds a key position because the way land is used bears consequences for the hydrosphere, climate and biosphere (Chhabra et al., 2006). At the same time, food, materials and living space are provided for the greatest part by land. Land use is thus a prime example for the dilemma of global human-environment interactions. For example, agriculture produces food, but intensive cropland farming requires irrigation, fertilization and pest control (Keys and McConnell, 2005). This causes water shortages, excess nitrogen and phosphorus use, soil pollution and reduces biodiversity by shrinking habitats and eliminating certain species (Foley et al., 2005). Furthermore, next to logging, expansion of agriculture is one of the two most important drivers of tropical deforestation, which in turn affects the global climate (Foley et al., 2005). This illustrates, how powerful land use is. And while it can be systematically detrimental, it can be just as effective as a leverage point for mitigating many of these human-environment dilemmas through the design of sustainable, integrated land use systems. For this reason, concepts such as sustainable intensification (Struik and Kuyper, 2014), climate smart cities (Khare and Beckman, 2013) and climate smart landscapes (Scherr et al., 2012) emphasize that land systems can be designed to avoid, adapt to and mitigate environmental change. However, the complexity of land use change rarely allows for straightforward, simple solutions. Instead, there are many trade-offs between desired and undesired outcomes at different scales, for different people groups and for different environmental domains (Seppelt et al., 2013).

Land use policies and planning are a traditional way to influence land use by regulating and stimulating certain developments in order to manage trade-offs between satisfying demands on the short term while preserving integrity of terrestrial ecosystems in the long run (Lambin et al., 2014; Reid et al., 2006). For example, reforestation in Vietnam, China, Costa Rica and Bhutan was achieved with a combination of policy instruments that included land zoning to protect native forests next to stimulating alternative supply of wood products from forest plantations (Meyfroidt and Lambin, 2011).

Land use models are used to inform institutions on the effects of policies and also serve to foresee possible future challenges that society needs to respond to. Particularly on large spatial and temporal scales, where empirical work becomes more difficult or impossible (e.g. experiments), land use models help to examine questions of trade-offs and synergies between different policies or socio-economic pathways of production and consumption. They also aid to understand the distribution and quantity of land use types of the past or to project it into the future based on assumptions and frameworks of causality. In this dissertation, large-scale land use models are referred to in the sense of geographical, computational simulation of land use allocations (Heistermann et al., 2006) with a spatial extent beyond the local level. This, hence, includes meso- and macro levels of land use change from e.g. a province to the global level. Outputs of such large-scale land use models are not only used to investigate policies or scientific questions, they are also used to provide input for other global environmental models, e.g. climate change models (Prestele et al., 2017).

1.2 Research Challenges

Recent research indicates that there is a wide range of uncertainty in the outputs and even the starting points of global land use models (Alexander et al., 2017; Prestele et al., 2016). Both model validations as well as model comparisons have indicated the need to address the large uncertainties and differences in land use model outcomes (Brown et al., 2013). There is agreement in the literature, that the representation of anthropogenic dimensions in large-scale land use models is a critical component underlying some of this observed uncertainty, hence the urgent need for improvement of this aspect of land use modelling (GLP, 2005; Rounsevell et al., 2012; Verburg et al., 2016).

Based on a series of empirical studies for the Lao PDR (Laos), this dissertation contributes to advancing scientific methods to represent human dimensions in large-scale land use models. It is part of the research project GLOLAND which aims at integrating human agency in global land use models. The focus on Laos was chosen because on the one hand, the country is undergoing relatively fast and fundamental land use change which is driven by human decision making on various spatial scales. On the other hand, research networks to Laos were available within the GLOLAND project and allowed to operationalize and carry out a series of studies to investigate the overall research challenges and questions based on specific land use change patterns and trajectories.

The dissertation addresses three overarching research challenges that are relevant for Laos and for representing human dimensions in large-scale land use models in general: the multifunctionality of land for humans (Verburg et al., 2011), human decision making (Rounsevell et al., 2014; Stannard and Aspinall, 2011) and land use regime shifts (Filatova et al., 2016; Müller et al., 2014). The following subchapters introduce the three overarching challenges in detail and provide a rationale of why these challenges were chosen to contribute to the improvement of the representation of anthropogenic dimensions in land use modelling.

1.2.1 Representing the Multiple Functions of Land

Any modeling activity is strongly dependent on the information available to feed the model. In spatially explicit, geographic land use models the key input are maps or spatial datasets describing the distribution and types of land uses of an area. What is not on the land use map will not be modelled and therefore is at risk to be ignored in decisions on natural resource management.

The best available and, therefore, mostly used maps are land cover assessments derived from satellite images and other remote sensing products (Verburg et al., 2011). Even though they improved considerably in the past years in terms of temporal and spatial resolution and analysis techniques for sophisticated indicators, the categories of land cover maps often fail to represent the multifunctionality and the multiple semantics of the same piece of land (Comber, 2008; Comber et al., 2008). For example, an area in the Bolivian Amazon that was classified as primary forest in a scientific categorization based on indicator plants was at the same time an old fallow plot for indigenous people (Wartmann and Purves, 2018). The categorization as primary forest raises the interest of global institutions to prohibit any human use in order to protect biodiversity. This is how mapping influences local realities with legal implications when only land cover data are utilized to make assessments.

Another pitfall of land cover maps, is, that the kinds of actors connected to a piece of land are not distinguished. For example, the category ‘agricultural land’ in a land cover classification could either be managed by smallholders or by a multinational company. However, this has completely different social, economic and environmental implications and hence important information for the analysis or simulation cannot be represented.

Dynamic land uses with multiple functions that are not clearly distinguishable as either forest or agriculture also ‘fall through the cracks of land cover analysis’ (Heinimann et al., 2017). Shifting cultivation is such a dynamic, century old land use practice in the tropics that involves the use of forest in different succession stages: e.g. old fallow, young fallow and actively cultivated plots (Schmidt-Vogt et al., 2009). Because it combines several land cover types over time, it can hardly be captured by a single land cover assessment (Heinimann et al., 2007). The lack of knowledge on the spatial extent and population living from shifting cultivation hampers the analysis and governance of a land use practice that is controversial and high on the political agenda (Fox et al., 2009; Mertz et al., 2009a; Van Vliet et al., 2012). The preparation of plots by slash and burn management is connected with major forest fires, greenhouse gas emissions and respiratory problems of residents in the region. At the same time, the land use practice sequesters carbon through the temporary regrowth of vegetation, buffers soil erosion and soil degradation if plots are left fallow for long enough for the soil to stabilize and recover (Hett et al., 2012). Moreover, it sustains many of the financially poor inhabitants of tropical countries with food, feed and fiber (Heinimann et al., 2013; Kilawe et al., 2018; Mertz et al., 2009b; Vongvisouk et al., 2014).

Putting multifunctional landscapes and land uses on the map will improve the visibility of land use systems with multiple functions and their actors and, therefore, make it possible to include them in land use models.

1.2.2 Representing Human Decision Making

Representing the complexity of human decision making within large-scale land use models is an overall challenge that, when looking closer, arises from a series of further, interconnected challenges.

In most current models, there are two issues with the way human influence is represented. First, there is no model-internal feedback loop from land use changes to changes of human behavior and back to land use change (Rounsevell et al., 2014). An example for such a full feedback loop would be large-scale deforestation in the Amazon upsetting civilians who may push for new regulations and a change of consumer behavior towards certified wood products. The feedback loop closes when the regulations and demand for sustainably managed forests triggered afforestation and reforestation. The lack of socio-ecological feedbacks in large-scale land use models can be understood by looking at the history of this field of science. Many land use models have been developed as an extension of Dynamic Global Vegetation models (DGV); human pressures on the environment were added only after a while as an external factor to the vegetation system dynamics (Müller-Hansen et al., 2017; Rounsevell and Arneth, 2011). In reality, the societal, economic and political responses to land use change are important new factors influencing land use change as new institutional arrangements emerged such as the United Nations program on Reducing Emissions from Deforestation and Forest Degradation (REDD) (Brondizio and Moran, 2013). In most land use models, these changes of institutional drivers and demands are scenarios fed to the model as an exogenous driver, rather than a result of the model internal feedback dynamic of the socio-ecological system (Eitelberg et al., 2016). Consequently, a first sub-challenge is to design a different or adapted model framework of large-scale land use models that represents how societies react to environmental changes in their consumption and production decisions.

The second problem is, that the current, large-scale models assume a single, universal type of human behavior while in reality, individual decision making and interaction between actors varies widely given the context of the decision situation (Rounsevell et al., 2014; Rounsevell and Arneth, 2011). This may seem like a technical issue of simply representing all possible ways of behavior, but Müller-Hansen et al. (2017) disentangle the problem as having more fundamental roots in differences of epistemology and research paradigms: the social sciences are not developing universal theories like the natural sciences do, precisely because human behavior is strongly context dependent. This means there are multiple theories of individual and collective human behavior and this plurality of theories forms a second challenge for integrating decision making into earth system models and large-scale land use models. In other words, there is no universal social theory crossing scales and contexts. It is up to the modeler to decide which theory to select given the model purpose and system dynamics of interest (Müller-Hansen et al., 2017). Agent-based land use models are a promising methodology in this respect as they can represent the socio-ecological dynamics that emerge from individual behaviors, agent interactions and the contextual environment (An, 2012; Evans et al., 2011; Parker et al., 2003; Schlüter et al., 2017).

However, a third problem that hampers the building of large-scale land use models (i.e. including global agent-based models) is the lack of datasets on land use decision making covering a global extent (Rounsevell et al., 2014). This data is not only needed for model parameterization. In order to advance theory development of land systems and the feedbacks from land use change to human behavior, the empirical models require further independent data to evaluate model performance through calibration and validation (O'Sullivan et al., 2016). At the bottom line, spatially explicit datasets on human behavior in socio-ecological context are pivotal for representing human decision making in large-scale land use models.

Developing a dataset for a global typology of decision making at different scales may be inefficient, given that human behavior and preferences can change rather quickly, even after a long period in which opinions were locked into the same way of thinking (Scheffer, 2009). Also, simply adding social theories to models originating in natural science may not be beneficial, since many social science theories have been developed with little focus on human - environment interactions. Instead, a fruitful alternative may be to think from the start of an integrated socio-ecological system in which the social and natural dynamics emerge or shift together (see also land use regime shifts). To develop knowledge and databases about the role of human decision making in socio-ecological systems, new methods are needed to collect data on land use decision making and scale it up – together with its socio-ecological context.

1.2.3 Representing Land Use Regime Shifts

Profound transformations from one enduring land use dynamic to another are called land use regime shifts (Ramankutty and Coomes, 2016). Such transformations occur for example at a location where subsistence agriculture changes into commercial agriculture. There are numerous examples of regime shifts for the past and they are expected for the future, but current land system models face limits in predicting abrupt land use regime shifts (Müller et al., 2014). On the one hand, this is related to the limited predictability of the causal factors (e.g. political or social transformations). On the other hand, Ramankutty and Coomes (2016) attribute this to the land system science community having focused mostly on regime internal dynamics to date.

The challenges are both of theoretical and technical nature. This implies that both knowledge about land use regime shifts, and methods to explore and represent them in models are needed.

1.3 Goals and Research Questions of this Thesis

The overall goal of this thesis is to improve large-scale, spatially explicit land use models regarding aspects that are relevant to better represent human-environment interactions. As such, the thesis works towards answering the question: How can large-scale land use models be improved to better account for human agency and decision making?

Specifically, the thesis examined the following research questions:

1. How can multiple functions of landscapes be represented in land use data and models?
2. How can human decision making on land use be represented, analyzed and scaled up in its socio-ecological context?
3. How can land use regime shifts such as the maize boom in Laos be modelled?

1.4 Research Design

1.4.1 Laos as a Case

The research of this dissertation focuses on Laos because the country experiences rapid land use changes that are driven by human decision making on local, regional and national scales.

Laos is known as a landlocked country with low population density and a richness in forests, minerals, water and biodiversity. These natural resources have been declining after a centrally planned economy was abandoned and market economic principles were gradually adopted from the mid 1980ies (Sandewall et al., 2001). For example, forest cover declined from ca. 50% of the total surface of Laos in 1982 to 41% in 2002 (Phompila et al., 2017). Poverty rates are declining from 30% in 2005 (Epprecht et al., 2008) to 24.6% in 2011 (LSB, 2016). With about 77%, the largest part of the population works and lives from various forms of agriculture (LSB, 2012) and a substantial part of particularly northern Laos is used for shifting cultivation (Messerli et al., 2009). Land use policies are therefore key for the government of Laos to address economic productivity from primary production, and to tackle poverty and environmental issues (Ducourtieux et al., 2005). How to navigate the needs and trade-offs between short-term and long-term growth via sustainable land use practices has been at the center of debates (Lestrelin et al., 2012; Messerli et al., 2015a; Vongvisouk et al., 2016).

Land use regime shifts occur at several levels in the country. At the national and regional level of Southeast Asia, agrarian transition processes lead to profound, complex transformations from a subsistence oriented to a commercially oriented agrarian society since the implementation of market principles in the 1980s (Baird, 2009; Castella et al., 2012; Rigg, 2009, 2005; Thongmanivong et al., 2009). In line with regional trends, a surge of land acquisitions of powerful foreign and domestic investors has taken place in several parts of the country after the year 2000 (Baird and Fox, 2015; Schönweger et al., 2012). Smallholder farmers were also engaged in crop booms. In Laos, the most prominent boom crops recently were banana, rubber and maize (Friis and Østergaard Nielsen, 2016; Lu, 2017; Thanichanon, 2015).

1.4.2 Research Approach and Thesis Overview

A red thread connects all studies in this cumulative dissertation, not only due to its geographic focus on Laos, but also because of the overall research approach (Figure 1.1). To address the interdisciplinary research questions, both quantitative and qualitative methods were used in order to inform and complement each other. Approaches, data and insights developed in chapter 2,3 and 4 culminated in chapter 5. Furthermore, each of the chapters 2-4 deal with at least two of the three research challenges and chapter 5 responds to all research questions and challenges simultaneously (see Table 1.1.).

The objective of chapter 2 was to operationalize the concept of land systems by developing a national scale classification of land systems in Laos that captures different types of agricultural and forest systems. It merges existing datasets in a GIS environment according to a heuristic decision tree and an expert survey. The resulting national scale land system classification maps multifunctional land uses and the variety of land use decision makers in Laos that are not covered in common land cover analyses.

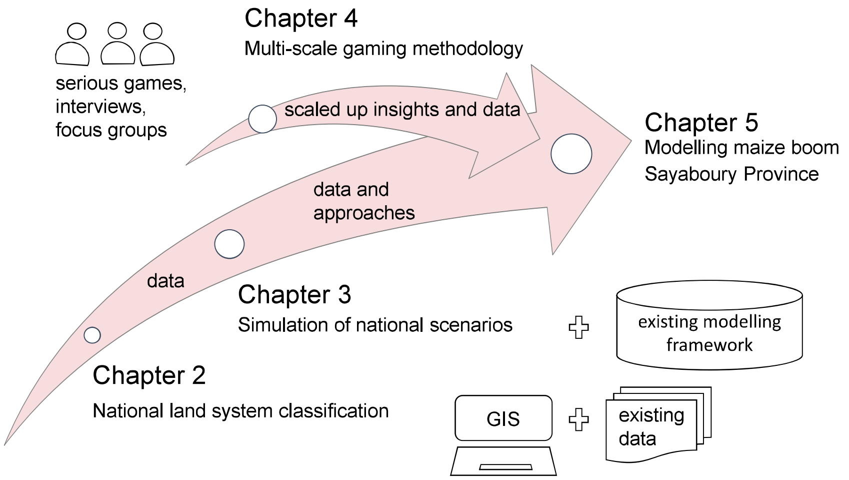

Figure 1.1 Overall research approach

The aim of chapter 3 was to implement a modelling approach to represent land system changes in the context of Laos and simulate future transitions in land systems for three different scenarios. It uses the land system classification of the previous chapter as a basis to parameterize a new application of the CLUMondo model together with further existing data. It develops scenarios and simulates their trade-offs between different political-economic development pathways and consideration of cultural ecosystem services and biodiversity protection.

The objective of chapter 4 was to develop and apply a novel empirical approach for (1) gaining insight into the history and immediate contexts for the decisions of smallholders at the household and village level and (2) to synthesize and upscale these insights to the main factors at the regional, emergent level of the maize boom in northern Laos. For this, field work with participatory approaches was conducted including serious games, interviews and focus group discussions across 7 different villages in 4 provinces of northern Laos. This led to the development of the multiscale gaming methodology.

The objective of chapter 5 was to analyze the causal effects of economic, geographic and policy factors on the spatial pattern of a crop boom. To achieve this, the land system classification method and some data collected for chapter 2 to set up a new model application for the regional scale with the same modeling framework as in chapter 3. The understanding and part of the data gained through the multiscale gaming methodology of chapter 4 is used and expanded in Chapter 5 to advance knowledge on the causes behind the

Research Challenges	Chapter 2 Land system classification	Chapter 3 Scenarios of alternative demands	Chapter 4 Multi-scale gaming methodology	Chapter 5 Crop boom model	Chapter 6 Synthesis
Multi-functionality of land	✓	✓		✓	✓
Human decision making	✓		✓	✓	✓
Land use regime shifts		✓	✓	✓	✓

Table 1.1 Overview of chapters in relation to the three overall research challenges and questions

maize boom through spatial land use model simulations.

The synthesis takes stock of the contributions of each chapter to the research challenges and reflects on methodologies and potential societal use of the knowledge gained in this dissertation.