

Participatory Bayesian networks reveal site-specific causes of land-use trajectories in Southeast Asia

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Abstract: Understanding local land-use trajectories is of vital importance for designing and implementing REDD+ projects. But such understanding is often marred by difficulties to relate to the effects of broad-scale underlying causes on local land-use responses. In this research, we used participatory data collection methods to calibrate Bayesian networks in order to study land-use change at the household and village level. We extracted historic land-use change trajectories from focus group discussions to identify the underlying causes of major land-use transitions with a focus on changes in forest cover and forest quality. These insights were used to construct influence diagrams consisting of the underlying and proximate drivers of change at different scales and for all sites. We studied six villages in mainland Southeast Asia, two in Laos, Vietnam, and China, respectively. The results suggest that changes in forest land use were shaped by a similar set of influencing factors, but with fundamental differences in the significance and importance of specific causal structures across the six villages of the three countries. REDD+ projects ought to consider such variation with a flexible implementation structure that accounts for site-specific dynamics.

Keywords: REDD+; deforestation; forest degradation; Bayesian network; participatory research

1 INTRODUCTION

Deforestation and forest degradation are driven by a complex interaction of proximate and underlying causes. Macroeconomic framework conditions impact on locally and regionally-specific driving forces that shape land use change. The underlying drivers are translated into immediate causes by the institutions in place, the transport and service infrastructure, market forces, and technological endowments. This combination of drivers affects the decision parameters of land managers results in management changes, and may lead to the changes in forest integrity (Geist and Lambin 2002, Angelsen and Kaimowitz 1999). These processes are highly place-specific, but may also repeat in similar manner in different localities. Moreover, changes in forest cover and quality may also exhibit non-linear responses to changes in external framework conditions, such as when continuing increases in crop prices triggered rapid and large-scale expansion of commercial agriculture into previously forested areas. Understanding this causal complex is a precondition for designing adequate management and policy instruments to gear land use towards sustainable pathways. Yet it is still unclear how the underlying causes of land use change are linked to the local decision making of land use actors (Turner, Lambin and Reenberg 2007).

The large diversity in underlying and proximate drivers of land use transitions needs to be reflected in national approaches for reducing emissions from deforestation and forest degradation plus the enhancement of forest carbon stocks

(REDD+). Such insights need to encompass a place-based understanding as a key input into national policy strategies that address the drivers of land use transitions (Wertz-Kanounnikoff and Angelsen 2009). Knowledge of the decision-making processes that lead to changes in land use is hence prerequisite to understand the likely impacts of REDD+ payments on the drivers of forest carbon emissions and to provide reasonable estimates of future emission levels. This includes recognizing the drivers of deforestation and forest degradation that are exogenous to rural communities, because understanding these is required for making prospective projections to sketch the likely future emission trajectories.

Moreover, a profound understanding of the causes of change in and within forested areas will support setting adequate and development-adjusted baselines that in turn can be used to guide the establishment of crediting baselines. The baseline setting is crucial for potential benefit sharing mechanisms. In addition, an incorrect placement of the recipients on the forest transition curve can lead to gross over- or underestimation of potential future emissions from deforestation and forests degradation. In sum, understanding the proximate and underlying causes of deforestation and forest degradation is paramount to adequately anticipate the likely effects of REDD+ payments to conserve forest cover and quality and hence to judge the effectiveness of programs and projects.

Promising scientific advances have been made in the study of the proximate causes of forest changes, but few studies integrate the complexities inherent in land-use change at local level. For example, agent-based models are powerful tools to better understand underlying causal structures and were successfully applied in REDD-type circumstances (e.g., Matthews 2006, Castella, Trung and Boissau 2005). But such approaches suffer from high data and calibration requirements, which compromise their transparency and applicability for larger areas. Econometric models on the other hand are powerful tools in studying regional and sub-national determinants of forest change, but have limited ability to account for nonlinearities, uncertainty, and dynamic interactions among the influencing factors. Yet, while REDD is likely a national program, its implementation will require sub-national verifications of emission reductions as well as local-level demonstration activities, because emissions are ultimately caused at the local level. Understanding the decision making of local land managers and communities will hence be a key component of future REDD+ schemes.

To better understand local land-use decisions we combined various participatory approaches for data elicitation such as participatory mapping, group discussions, and transect walks. We used this rich information to construct a causal Bayesian network that serves to extract the proximate and underlying causes of the historic land-use trajectories that were identified by local stakeholders. We tested this hybrid approach at the village and household level in mainland Southeast Asia with data from six villages in Southwestern China, Central Vietnam, and Northern Laos.

2 MODEL

We utilized a participatory modeling approach centering on Bayesian networks (BNs). First, we assessed local land-use changes using participatory mapping and approximated historical land-use changes in focus group meetings with a focus on the last 20 years and on changes related to forest cover and forest quality. Second, we facilitated the identification of the drivers of major changes by local stakeholders and used this information to construct influencing diagrams that visualize the causes of land-use change. Finally, we calibrated the BN with data from a large household survey that yielded representative data on the socioeconomic endowments, which emerged in the discussions as influential forces of past and potential future land-use change.

2.1 Bayesian Network

A Bayesian Network (BN) is a directed acyclic graph (DAG) that encodes probabilistic relationships among the variables of interest (Jensen 2002, Pearl 2009). A BN consists of two parts: the network structure (the DAG), i.e., the variable connections with directed arrows, and the parameters, i.e., the conditional probability tables (CPTs) that are associated with each variable and quantify the influence of the causal variables. Each variable in a BN denotes an attribute, feature, or hypothesis about an uncertain event with a set of state values, which are often discrete, mutually exclusive, and collectively exhaustive. The arrows connecting variables represent directional influences that typically depict a cause-effect relationship. Hence, BNs encode probabilistic relationships among variables of interest with a graphical interface that provides a natural and intuitive way to model causal reasoning based on Bayesian statistics (Jensen 2002, Pearl 2009, Heckerman, Geiger and Chickering 1995).

BNs offer multiple advantages in representing land-use change processes driven by intertwined factors. First, the capability of knowledge representation and inference under conditions of uncertainty makes BNs an appealing tool. The ability of BNs to model causal connections between factors that shape land-use change is particularly valuable for our purposes because it allows us to draw inferences about the local land-use outcomes based on different scenarios. Second, BNs can incorporate the qualitative beliefs and attitudes of stakeholders and existing research results along with quantitative data (Marcot et al. 2001, Newton et al. 2006). BNs can effectively facilitate focus group discussions via the graphical interface and the influence diagram, which support the active involvement of stakeholders in model calibration and validation. The influence diagrams are also relevant for decision makers because they are transparent, intuitive and easy to understand. In summary, the flexibility of BNs in combining quantitative evidence with stakeholder information renders them an ideal tool to illustrate land use change process.

BNs model development consists of two tasks: the construction of the network structure and the estimation of the parameters (i.e, the CPTs). In this research, we derived the structures of BNs, i.e., the factors influencing the land use change and how they interact, based on the knowledge gained from villagers and local experts through group focus discussions. The parameters of the network were calibrated with demographic and social-economic endowments of household from survey data.

3 DATA

We selected six villages with comparable biophysical settings and with socialist governments in upland areas of mainland Southeast Asia. The two villages in Laos are located in Nam Et-Phou Loey national park, the villages in China are situated in Xishuangbanna prefecture, and the villages in Vietnam in Nghe An province close to Pu Mat national park. Both qualitative data and quantitative data were collected at household and village level in all villages and with similar data elicitation strategies. The qualitative data were collected in focus group discussion with 6 to 12 villagers of different ages and sexes and capture main processes and patterns at village level. Village-level discussions included participatory mapping of major land use categories, approximation of the major land-use change trajectories, and the construction of a network that links livelihoods with land use and changes therein.

The land use maps were sketched by villagers on a transparency overlaid on a plot of topographic maps or very-high-resolution satellite images. The participatory

land-use maps reflect the current spatial configuration of major land uses and major changes in land use in the past 10 to 20 years. This qualitative map was mainly used to facilitate subsequent discussions.

We sketched land-use transition curves for the major land-use categories identified in the mapping exercise with trend lines that approximate historic changes over the last 30-50 years. We also inquired about expected future trends of land use. Villagers first indicated important milestone events and, based on these, temporal changes in population such as major policy changes in agriculture or forestry. Based on the transition curves we discussed the changes of land use categories as well as their causes, again in the past and for the future.

Finally, together with participants, we constructed a land use-livelihood network to illustrate the major cash income and consumption needs such as, food, fuelwood, and timber. The network connects the livelihood sources with their associated land-use categories and was used to discuss how important changes in external framework conditions instigated subsequent land-use responses. Figure 1 exemplifies the output from the qualitative data collection strategies.

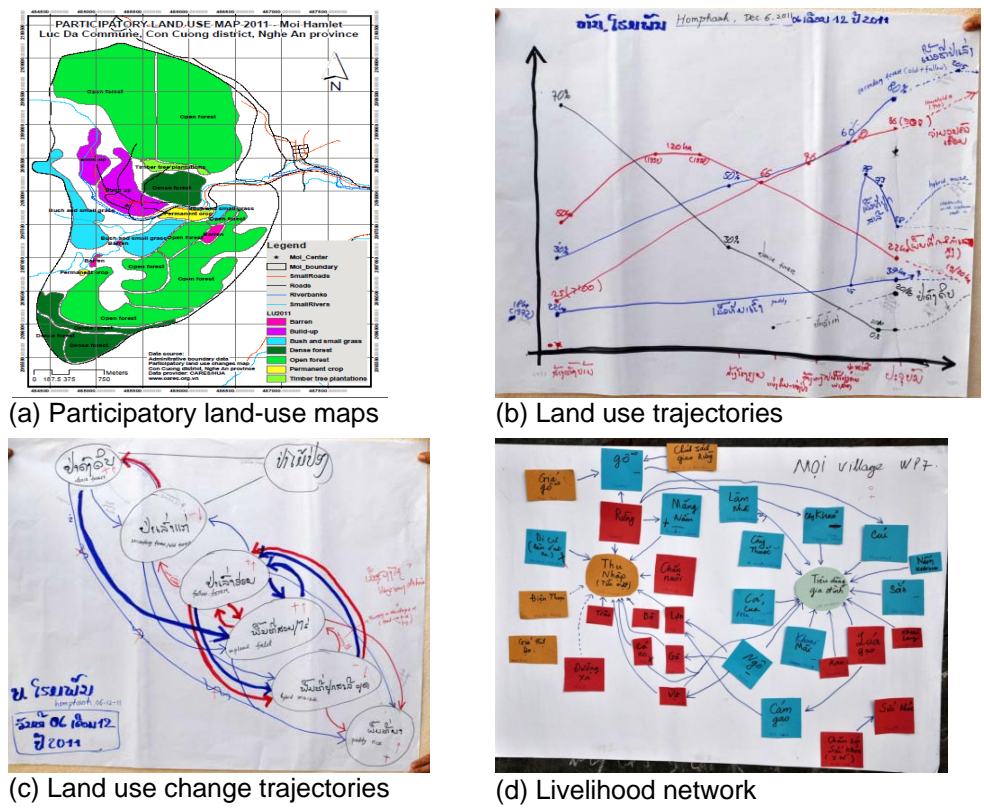


Figure 1. Qualitative data collected by participatory approaches

To complement these qualitative data, we also conducted a household survey in each village with a structured questionnaire to supplement qualitative data with quantitative household evidence. The questionnaire covered demographic changes, labor allocation, assets and income, agricultural production, and the use of forest products. We conducted roughly 50 interviews per village, more than 300 in total.

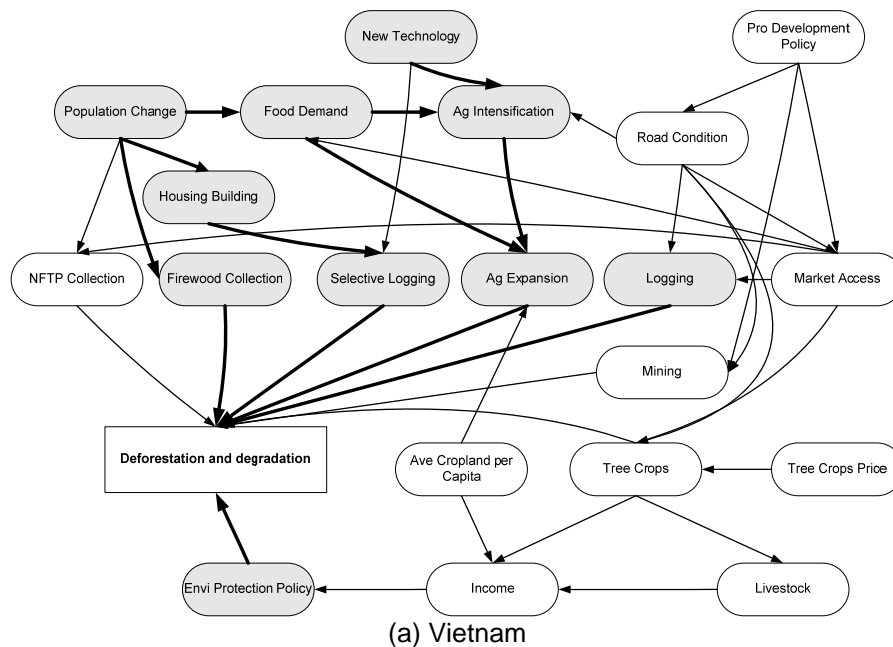
4 RESULTS

The variance between the two surveyed villages of each country is found insignificant, thus the results analysis is focused on comparisons across countries.

Country comparisons demonstrate that until about 15 years ago shifting cultivation, frequently augmented by paddy rice production, dominated land use in all study villages of Vietnam, Laos and China. But land-use pathways diverged notably during the last 15 years and most villages underwent considerable changes in land use and livelihood pathways.

Figure 2 illustrates considerable differences in the pathways of land-use change in the three countries. The villages in Laos are dominated by shifting cultivation, high population growth, and considerable pressure on remaining secondary forest resources. The recent development of new technologies, e.g., the introduction of hybrid maize on the shifting cultivation plots, facilitated increases in cash income and induced a shortening of fallow periods. The study sites in Vietnam experienced a transition from shifting cultivation to permanent agriculture in response to government discouragement of clearing land by fire. Some areas formerly used for shifting cultivation were replaced with tree plantations for timber production. Concurrently, significant selective extraction of timber for cash income occurs within natural forest areas. In China's Xishuangbanna prefecture upland fields and fallow forest areas that were previously used for shifting cultivation have been entirely replaced with rubber plantations in the last ten years. Rubber was at first introduced by the government, but the recent rapid growth of rubber plantation was caused by commodity price increases. The boom in rubber also led to considerable conversions from secondary and dense forest areas (cf. Ziegler, Fox and Xu 2009) and rubber planting is still expanding where suitable land is available.

The different pathways led to considerable variations in the spatial patterns of land use among villages. Laos is dominated by the classical patterns of land-intensive shifting cultivation systems. Vietnam shows complex mosaic landscapes of permanent plots and considerable forest degradation in accessible areas. Yet, the most ubiquitous landscape changes occurred in China where the expansion of rubber and, to a lesser extent, banana dominated land use. We can hence see an interesting trajectory from largely subsistence-based shifting cultivation, to sedentary small-scale farming augmented with tree plantations, and intensively managed land-use systems that rely on cash tree plantations.



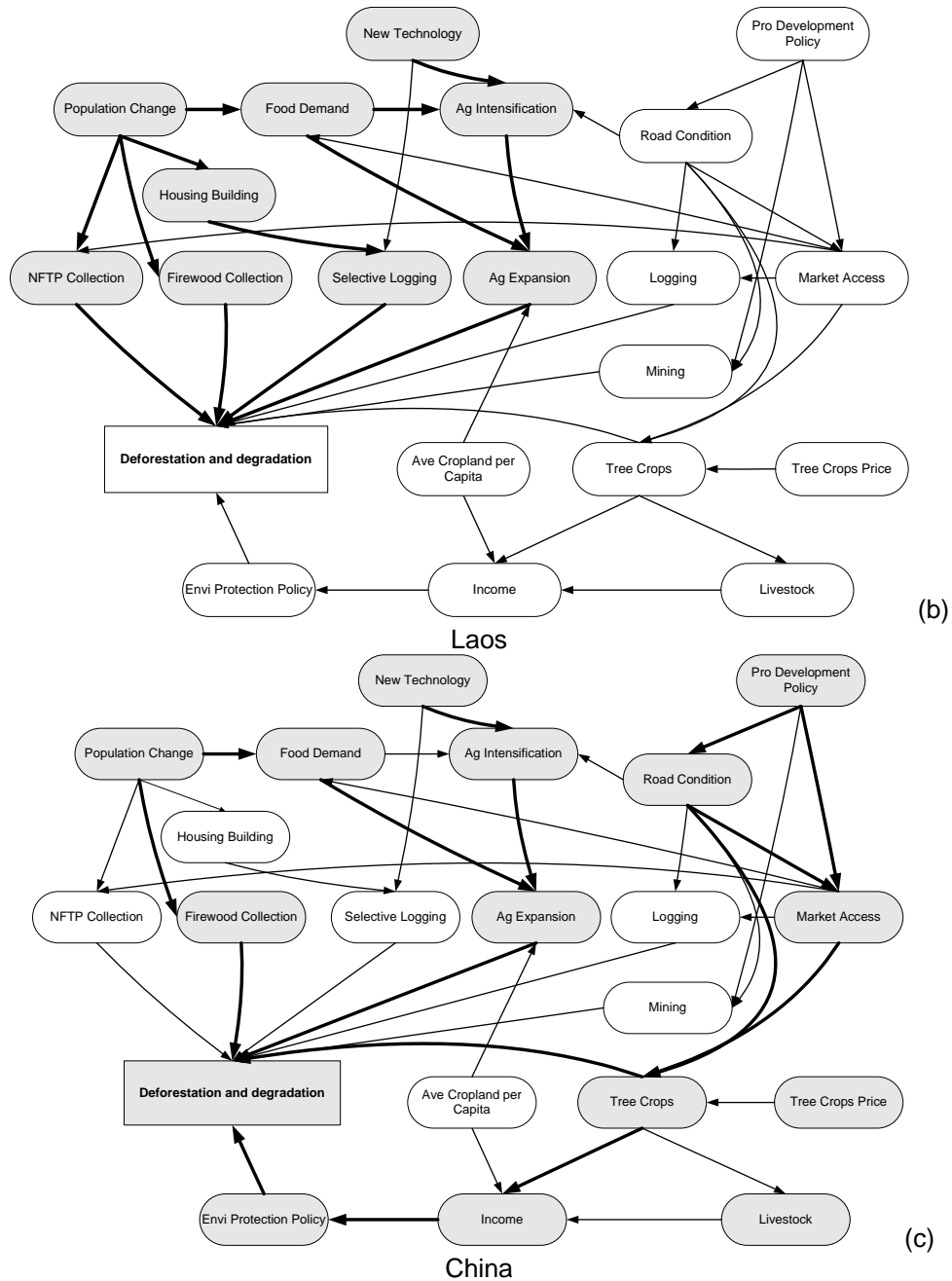


Figure 2: Land use change pathways:
Major drivers and their interactions in each country are highlighted using dark colour background and thick arrows

The areas used for agriculture and forestry remained relatively stable since around the year 2000 in all three countries without significant expansion of agriculture into previously uncultivated lands. Dense and old-growth forests enjoy some degree of protection by the State or communities, but forest degradation is pervasive in all sites mainly due to decreasing fallow periods in shifting cultivation systems, selective logging, and considerable extraction of firewood and non-timber forest products. The study sites hence present an interesting transect of land-use systems that can be connected to contrasting trajectories of changes in agricultural and forest uses (Figure 3). Economic returns from land use are by far the highest in China with the most intensive land-use systems in terms of labour and capital inputs, but also with the lowest quantity and quality of forest remaining. Land-use intensity is intermediate in Vietnam with less land and capital inputs per household

while the study sites in Laos are dominated by high inputs of land, but low labour and capital intensity per unit of land.

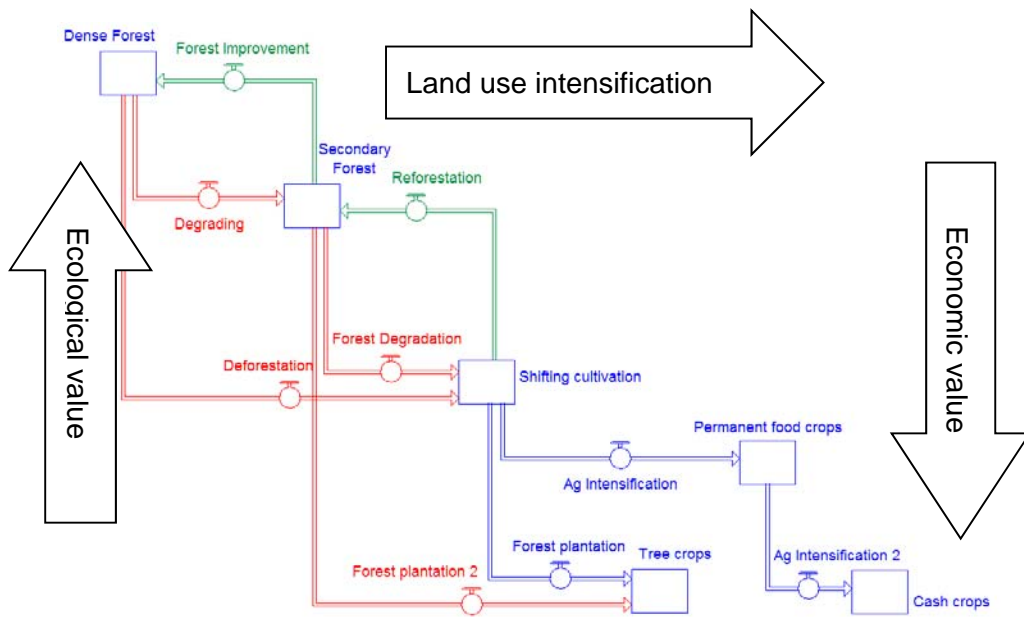


Figure 3: Land use trajectories: trade-off between ecological and economic values

5 CONCLUSION

A thorough place-based understanding of the underlying causes of land use change is essential to formulate sound land-use policies. This is particularly imminent for initiatives related to REDD+ that rely on the formulation of effective, efficient, and equitable economic compensation mechanisms. We therefore strived to disentangle the underlying causes for three sites in mainland Southeast Asia that are similar in their biophysical characteristics, yet differ considerably in their recent history of land use transitions.

The COP 16 in Cancun agreed on the need for developing national systems for assessing reference emission levels for changes in forest carbon (Bernard and Minang 2011). But the most probably way forward for most countries will be the establishment of sub-national reference levels and crediting baselines. Therefore, a better understanding at local level is an essential input into REDD+ as it improves a process-based understanding of the potential impacts of benefit sharing on forest carbon storage. Local-level investigations are particularly important for processes related to forest degradation that to date pose high challenges for monitoring at larger scales. Hence, local understanding of pathways and causes of land use change will likely be a crucial element of future REDD+ strategies in a nested approach (Pedroni et al. 2009), especially with regards to the assessment of more subtle modifications that characterize the second “D” and the “+”.

The modelling approach presented in this paper suggests combining a number of participatory data elicitation methods with quantitative data collection. The integration of these data in a Bayesian network allows the qualitative visualization of cause-effect relationships as well as quantitative inferences. Such models are well suited for stakeholder interaction at local level and can provide important “ground-truth” for informing sub-national REDD+. Moreover, the comparison across sites revealed the large variation of transition pathways of land use despite very similar biophysical and political settings. This demonstrates the importance of recognizing the diverging causes and patterns of local land-use trajectories, because different REDD+ strategies are required in setting reference and crediting

baselines to ensure the additionality of carbon payments, address permanence, and assess co-benefits.

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