Agent-Based Simulations of Smallholder Decision-Making in Land Use Change/Cover (LUCC) Problem

Case Study: Agricultural Land Conversion in Jambi Province, Indonesia

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Abstract Land conversion is one complex problem which includes actors and factors with different social levels. In the process of land use change, every small change in decision-making methods used by individuals may significantly affect the outcomes. Agent-based modeling and simulation (ABMS) is a common approach to analyze and simulate the process of land use change as the result of individual decisions. This paper firstly describes the general problem of agricultural land conversion (ALC) in Jambi Province, Indonesia, in particular in connection to the smallholders' role. It is then followed by the brief explanation on factors influencing the smallholders' behaviors. Then, conceptual framework of ABMS in analyzing land conversion as one kind of the land use change/cover (LUCC) processes is presented enriched with agent topologies and the decision-making processes on the agricultural land conversion problem. Finally the proposed model is illustrated through a preliminary case study in Jambi Province, and some scenario on the effect of interaction between farmers and government is described. The framework is still a general approach to analyze simple LUCC problem using ABMS approach.

Keywords Agent-based modeling and simulation • Decision-making • Food security • Land conversion • Land use/cover change

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1 Introduction

In making decisions of the use of land, individuals face a complex environment that consists of interacting elements including both natural and human systems. The elements of natural and human systems that influence land use decision may be very complex. In the natural systems, land use decision-making mostly depends on the dynamic process of the nature, for instance, how the hydrological cycle works and how the distribution of biological resources applied in the specific area would differ from other area. Moreover, the social elements of human's environment can also influence the options and incentives that are available to the individual and the land use decisions they make.

Land use problems usually arise when there are significant changes in land use [1]. Land conversion often is associated with problems such as loss of farmland, food security problems, and other issues. There are a lot of land conversion types, but in this paper the focus will be on the conversion of agricultural land into land used for agro-industrial investments, especially on rubber and oil-palm plantation.

As the computer simulation technologies are developing, social scientists have provided a tool not only for predicting the social phenomena of land conversion but also for better understanding the nature of the human systems involved in the phenomena. For years, a number of agent-based simulations (ABMS) have been designed to capture the dynamics of land use and land cover change (LUCC). It has been a powerful approach in the land use modeling community mainly because it offers a way of replacing transition probabilities or differential equations at one level with decision rules at a lower level along with the appropriate environmental feedback [11]. These simulations have focused on both abstract and real-world examples in which the actions and interactions of a collection of agents, representing individuals, households, or organizations, determine the overall patterns of land use change produced by the simulations. An agricultural land use change model example –"FEARLUS" – investigates how well different social learning strategies are employed [12]. Further, "LUCITA" explores how the characteristics of frontier families influence changing agricultural land use, and secondary succession, in the rain forest [13]. Existing models and simulations typically couple a human system, represented by a collection of agents making land use decisions, with an environment system, represented by a raster grid of spatially distributed land uses within the landscape, through agent-agent and agent-landscape interactions that feedback and alter the LUCC in the area of interest.

ABMS approach is used in this paper to model the decision-making process of smallholders when facing the land conversion choice. In the model, land conversion behavior of smallholders would be mainly triggered by three factors: external factors, internal factors, and social factors. The rest of the paper is organized as follows: it firstly describes the general problem of agricultural land conversion (ALC) using an example of the case in Jambi Province, Indonesia, in particular in connection to the smallholders' role. It is then followed by the brief explanation on factors influencing the smallholders' behaviors. Then, conceptual framework of ABMS in analyzing land conversion as one kind of the land use change/cover (LUCC) processes is presented enriched with agent topologies and the decision-making processes on the agricultural land conversion problem. Finally the proposed model is illustrated through a preliminary case study in Jambi Province, and some scenario on the effect of interaction between farmers and government is described.

2 Land Conversion Problem in Jambi Province

Despite the fact that land conversion is a phenomenon that is almost unavoidable during economic development and population growth periods [4], uncontrolled land conversion will have great impacts on environment and agricultural products [5]. Not only in the developing countries had the case of agricultural land conversion (ALC), it also speeded in the developed countries.

Agricultural development basically has two principal objectives, to increase agriculture production both quantitatively and qualitatively and to increase the farmers' income. In the Ministry of Agriculture of Indonesia strategic plan (2010–2014), there are five objectives of the agricultural development [2]: first, to realize sustainable farming system based on the local resource; second, to establish sustainable self-sufficiency (*swasembada berkelanjutan*); third, to grow the food security and food diversification; fourth, to have more added value of the agricultural products; and fifth, the most important one is to increase farmers' revenue and welfare.

One of the problems faced by the nation is the ongoing conversion of agricultural lands to various other land uses, such as agro-industrial plantation that are economically more profitable. Other examples of the conversion on land use in other sectors are industrial area, public facility, and residential building. The agricultural land conversions are not only expanding in the agriculture production center such as Java Island but also in other region such as Jambi Province. As an illustration, there is a total of 75,000 ha agricultural land converted to oil-palm plantation in Jambi by 2010 [3]. The land conversion was triggered by the increasing market price of oil palm and the ease of getting the cash income periodically.

The decreasing number of agricultural land in Jambi Province was at least caused by two main factors: (1) the conversion in land use from agricultural to plantations, especially oil palm and rubber, and (2) the idled activity of land which is not cultivated for some period of time (idled land). Of the two factors, the main factor, namely, the transition function of land into oil-palm plantations and rubber, becomes the dominant factor. Many of the oil-palm and rubber plantations in Indonesia were established by large companies. However, smallholder farmers who are involved use more than 40% of the total oil-palm and rubber land [3]. Earlier, smallholder rubber and oil-palm cultivation were encouraged and supported through specific government support, but such policies are now terminated, and nowadays smallholders establish and manage their plantations independently. These land conversion decisions made by a large number of smallholders are more difficult to control than a large-scale land use transformation to companies.

3 Factors Influencing Smallholders' Behavior

In a paper examining behavioral change theory from an economic perspective, Prendergast et al. in the Scottish's government publication on agricultural and climate change [6] focus on three key drivers of behaviors: external factors, internal factors, and social factors. The factors would, if we apply it to the case of smallholder decision in the ALC phenomena, affect the decisions of smallholders, as social beings, including what to produce and how to produce it.

1. Internal Factors
   Based on [6], in smallholder farmer decision-making process, there are five keys to sum up in representing the internal factors: habit, personal capacity, framing and emotions, loss aversion, and immediate gratification and payoffs.
2. Social Factors
   Smallholder farmers' decisions are affected by the views and behaviors of their peers and neighbors as well as other family members and society at large [7]. Farmers are influenced by the behavior of their peer group. The literature shows that proficiently carrying out skilled farming improves both how farmers perceive themselves and how other farmers view them [7].
3. External Factors
   External factors are linked with monetary and effort costs – the affordability of choices, compared with the financial resources people have at their disposal, and the conditions which enable people to take advantage of these choices (such as accessibility or availability of information) or which act as barriers (complexity, inconvenience).

With reference to the aforementioned factors, we are interested in modeling the phenomena of agricultural land conversion done by smallholders with the following assumptions:

- *Smallholders are interested in the decision which offers an immediate gratification and payoffs.* In the previous works by Schwarze et al., it was stated that the oil-palm producers cultivate significantly more land than non-oil-palm farmers [8]. On average, oil-palm farmers cultivate 6.51 ha of land compared to 3.31 ha of non-oil-palm farmers, which is equivalent to almost twice the area.
- *Smallholders are affected by the behaviors of the neighborhood farmers.* The literature shows that proficiently carrying out skilled farming improves both how farmers perceive themselves and how other farmers view them [7]. Research by Diederen et al. [9] analyzes the choice of a farmer to be an innovator, an early (or late) adopter, and a non-adopter. The research found that structural characteristics explain much of the difference between types of farmer, and factors such as age and farm size and type may dictate whether and when adoption is a viable proposition at all. In addition, in the case of agricultural land conversion in Jambi, a survey found that smallholder farmers are aware to their neighborhoods' type of land, by means once the neighbor converts to the nonagricultural land, they have

the feeling of being insecure that their agricultural production will be possibly demolished by nonagricultural pests.

- *Smallholders who have sufficient economic support will tend to keep their agricultural land*. Smallholders argue that agricultural income has been insufficient in fulfilling the primary needs (housing, foods, and clothing) as well as the secondary needs (education, etc.) of their family [2]. To improve smallholders' sustainable livelihoods and agricultural practices, based on a baseline assessment and extensive stakeholder consultations carried out in 2011–2012 [10], the government of Indonesia is responsible for strengthening the smallholder aspect in such ways as strengthening local government agricultural extension worker systems to ensure sustainability and scaling up of successful solutions and working with smallholder cooperatives and larger plantations to reduce expansion into forests.

4 Purposed Mechanism

The model developed in this paper adapts the work of Robert Axelrod [10] known as the cultural dissemination phenomena. Axelrod models the adaptive model that reveals the effects of a mechanism of convergent social influence, based on the assumption that differences between individuals and groups exist. In his work, most neighboring sites have little in common with others and hence are unlikely to interact. However, when the two sites start to interact, they become similar and more likely to interact in the future. Over time, they share the same features, and it is shared over a larger area, and that represents how culture is disseminated over a group of agents [10]. The simulation model in this work is built using NetLogo (https://ccl.northwestern.edu/netlogo). Our purpose is to simulate the impact of smallholders' agent decision-making on the agricultural land conversion considering a simple behavior of the smallholders who own three factors (internal, external, and social) as an agent. The goal is to evaluate and compare the scenario's result, including some interaction with the government in supporting the smallholders in making the decision on ALC phenomena.

4.1 Agent and Environment

In the model, the only agents are represented by patches. Patches can't move, but otherwise they're just as "alive" as turtles [8]. There are two definitions of agents that will be used: smallholder agent and government agent. The variables owned by agents are listed below in Table 1, and the rule of interaction between agents is listed in Table 2, respectively. As agents, we defined that the farmers and governments are in a closed environment where their positions are randomly distributed. Though most of the works on modeling LUCC has engaged the spatial factor, in this model we focus on the social phenomena; thus, spatial considerations are excluded.

Table 1 Variables owned by patches

Variables	Definitions
Smallholder state	Smallholders' list of state of their own land
Government state	Government's list of features of their support
Money	Value of money to represent support and needs owned by smallholder and government agent
My neighbor	Neighbor of the patch

Table 2 Trait and value of each feature

Trait#	Trait	Value 1	Value 2
0	Type of land	Agricultural	Nonagricultural
1	Return	Less	More
2	Ease of process	Hard	Easy

Agent-based models consist of dynamically interacting rule-based agents. We model the smallholder agents based on these following rules:

When smallholder agents interact with other smallholder agents:

- One will be chosen to be active (random).
- Choose one of its smallholders' neighbors.
- Calculate choices similarity.
- With probability proportional to the choices' similarity, active site (smallholder) and the selected neighbor (smallholder) will interact with each other.
- Select a random feature on which the active site and its neighbor differ.
- Change the active site's trait on this feature with the neighbor's trait on this feature.

When smallholder agents interact with government:

- One will be chosen to be active (random).
- Choose one of its government neighbors.
- Calculate feature-choices similarity.
- With probability proportional to the feature-choices similarity, active site (smallholders) and the selected neighbor (government) will interact with each other.
- Check if there is any enough offer to be paid on the need of support. If it is, accept the support, by adding money with the value of the support and subtracting the same value to the government patch.

As for the government agent, agents are set to be interacting with smallholders only, and we model their rules as the following:

- Calculate feature-choices similarity.
- With probability proportional to the feature-choices similarity, active site (government) and the selected neighbor (smallholder) will interact with each other.
- Select a random feature on which the active site and its neighbor differ.

Table 3 List of each patch

	[2 2 1]	
[2 1 1]	[2 1 2]	[1 1 1]
	[1 1 2]	

Table 4 The percentage of traits of the middle patch

	33.33%	
66.66%	100%	33.33%
	66.66%	

- Check if there is any enough value to be paid on the need of support. If it is, give the support, by subtracting money owned with the value of the support and adding the same value to the smallholder patch.

4.2 Simulation Design

Each smallholder patch represents a state of each smallholder, and each government patch represents a feature of state of government support. The state of smallholder and state of government support of the agent are represented by a list of integers.

In this case, every patch owns a list containing three integers in the range of one to two. For example, here is a snapshot of four patches at a particular moment in Table 3.

Suppose the middle patch is one smallholder farmer, the inhabitant of the patch is a farmer who prefers nonagricultural land (2), less return (1), and easy process to get through agricultural products (2). Choices and feature similarity between two features can be defined as the percentage of traits they have in common. Table 4 represents the percentage of traits owned by the middle patch in common with each of its four neighbors.

5 Experiment Result and Discussion

5.1 Scenario 1: Smallholders Are Interacting with Smallholders, No Government Intervention

The simulation results are expected to illustrate the number of agricultural land and nonagricultural land (in unit) with different scenarios, while interaction only happens between smallholder farmers. Figure 1a shows the scenario results when there is no interaction between agents, so the number of agricultural land and nonagricultural land remains the same over a period of time. In Fig. 1b, we set the starting number of nonagricultural land more than agricultural land, and result shows that the number of agricultural land decreases over the period of time, while the nonagricultural land increases over the decreasing number of agricultural land. The list of feature is set to be random for the farmer agents. Lastly, Fig. 1c clearly

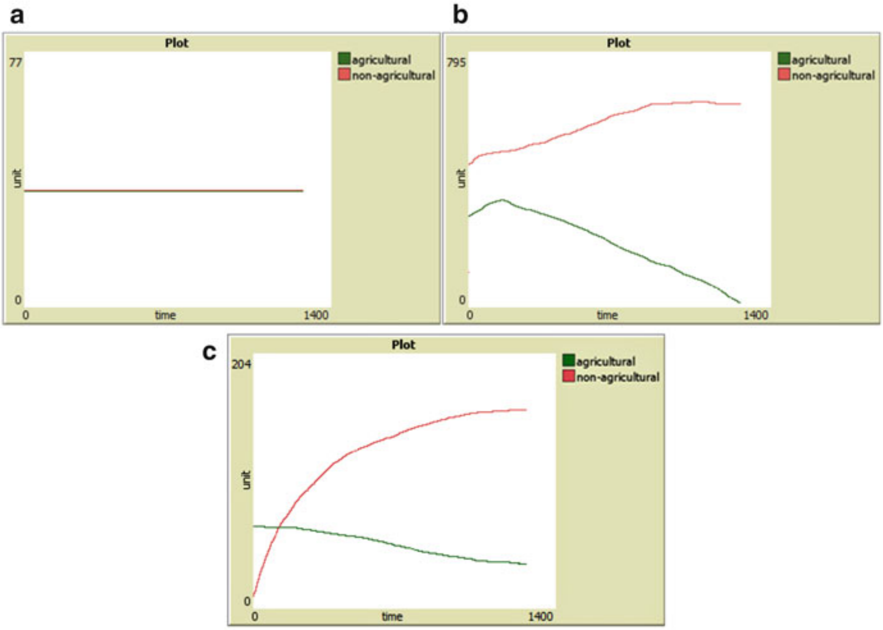

Fig. 1 Simulation results on smallholders' decision when (**a**) no interaction between other smallholders; (**b**) with interaction with other smallholders, with the number of nonagricultural farmers more than agricultural farmers; and (**c**) with interaction with other smallholders, with the number of nonagricultural farmers less than agricultural farmer

shows that the number of nonagricultural land will improve as agricultural land number decreases even when we set the starting number more. It summarizes that with the interaction between smallholder farmers and agricultural farmers tend to adapt to the nonagricultural farmer "culture," which own value "2" on the type of land trait with various values for other traits.

5.2 *Scenario 2: Farmers Are Interacting with Farmers and with Government*

The simulation results are expected to illustrate the number of agricultural land and nonagricultural land (in unit) with different scenarios, while interaction happens between smallholder farmers and also with the government. Government roles in this scenario are to offer their support (represented by number of money owned by each patch) and see whether the number of support needed by the smallholder can be covered by them to support them keeping their agricultural land. For the government agent, the traits are set to "1" value for the type of land traits. Figure 2a shows the scenario results when there is no interaction between agents, so the number

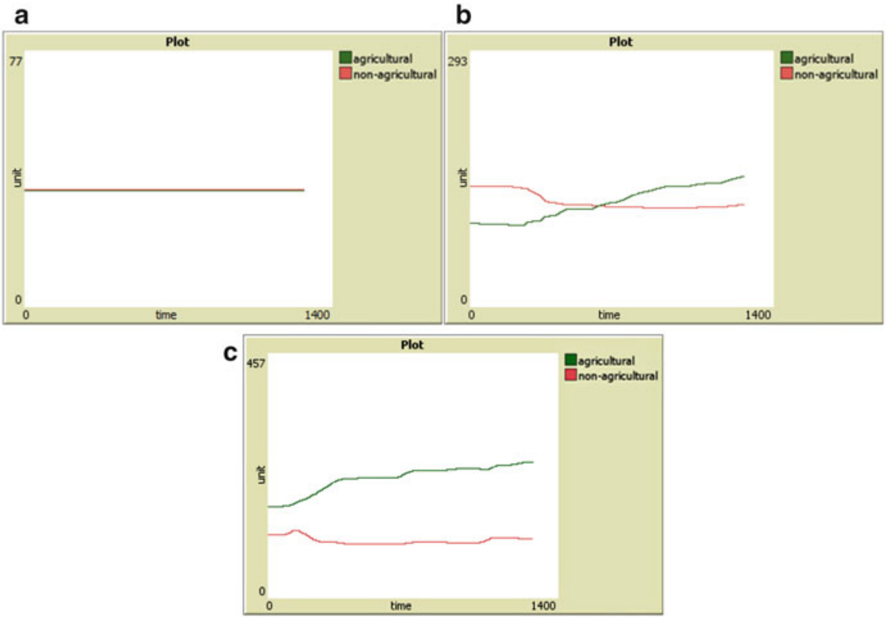

Fig. 2 Simulation results on smallholders' decision when (**a**) no interaction between other smallholders and smallholders with government agent; (**b**) with interaction with government, with the number of nonagricultural farmers more than agricultural farmers; and (**c**) with interaction with government, with the number of nonagricultural farmers less than agricultural farmers

of agricultural land and nonagricultural land remains the same over a period of time. In Fig. 2b, we set the starting number of nonagricultural land more than agricultural land, and result shows that the number of agricultural land increases over the period of time, while the nonagricultural land decreases over the increasing number of agricultural land. The list of feature is set to be random for the farmer agents. Lastly, Fig. 1c shows that the number of agricultural land will improve as the nonagricultural land number decreases by then. It summarizes that with engaging the government agent to the simulation, the smallholder tends to exchange trait with the government agent who also exchanges the number of value of money/support needed by smallholder.

6 Concluding Remarks

This paper use agent-based modeling and simulation (ABMS) approach to model a simple phenomenon on the agricultural land conversion (ALC) taking the Jambi Province as the case study. With several assumption on the smallholder agents about their driving factors of land conversion (internal, external, and social), we presented the result of simulation to see how interaction between smallholders and also between smallholders and government agent would have an impact on the number of converting land. Several findings are summarized by the following: (1) the interaction between smallholders without government (or other support) would have an impact on the increasing number of nonagricultural land, and (2) the interaction between smallholders with government (or other support) would have an impact on the increasing number of agricultural land. The simulation results go in line with the previous works on smallholders' behavior that in making decisions regarding land conversion, with some support and interaction with government, smallholder farmers might want to keep their agricultural land as long as they would have profitable production or they have basic support to avoid their land from idle production.

The work on this paper is a simple preliminary model on smallholder decision-making on land use change/cover process, but in the future, it is expected to be expanded with engaging more factors in the modeling process such as more agents to be included in the environment and more variables including geographical and spatial data to improve the validity of result to be implemented in the real world. Moreover, scenarios on government support would be improved by adding more value and possibility owned by the agent (not limited to economical support).

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