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Research Article

SYSTEM DYNAMIC MODELLING AND SIMULATION FOR CULTIVATION OF FOREST LAND: CASE STUDY PERUM PERHUTANI, CENTRAL JAVA, INDONESIA

Candra Musi[1*], Sutrisno Anggoro[2], Sunarsih[3]

[1] Environmental Sciences, Diponegoro University, 50241, Indonesia
[2] Fisheries and Marine Sciences, Diponegoro University, 50241, Indonesia
[3] Science and Math, Diponegoro University, 50241, Indonesia
* Corresponding author's e-mail: candramusi@perhutani.co.id

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ABSTRACT

The deforestation and forest degradation rates have a propensity to rise every year. The problems in pertaining with the issue is not solely preoccupied on the ecological concern but also to the socio-economic impacts. The complexity of forest management is a serious barrier in determining a better management policy. Modeling system is a simple method to describe the real situation in nature. A qualitative approach is used to identify the relationship between the dynamics of important behaviors. The causal relationships among the factors were investigated by using causal loop diagram. The model conceptualization was constructed by using a stock-flow diagram. The result of the simulation model was used to determine the alternative policies for better forest management. The results indicated that the tenant welfare would be enhanced through the provision of production-sharing by 25% and the Corporate Social Responsibility by 2%, which yields a reduction in cultivated area of 916.61 ha within a period of 67 years or a decline of land area by an average of 13.68 ha per year.

Keywords: dynamic model, tenant farmers, production sharing, forest land cultivation

INTRODUCTION

Convenient and healthy environment for life is the basic rights of every people. Forest as an ecosystem provides significant benefits for humankind including the security, basic needs fulfillment, health, social relationships, conservation, protection, and production functions (Alcamo *et al*., 2003) to support the establishment of a desired environment. Simon (2006) defined forest as an association of humankind, flora, and fauna, which is dominated by trees or perennial vegetation with a certain area width so as forming a micro-climate and specific ecological conditions. Soeriaatmadja (1997) explicated the influences of forests comprise of three interrelated environmental factors, namely climate, soil and water supply for various areas.

Collaborative Forest Management (CFM) is a forest management paradigm created based on the experience of professional foresters and local communities manifested in an actual partnership that might involve various parties (Carter, 2005). Castro and Nielsen (2001) asserted that Collaborative Forest Management is a collaborative institutional arrangement between various parties for the management of natural resources. Ingles *et al*. (1999) suggested the Joint Forest Management (PHB) is established simply based on the assumption that forest management would be effective if the local community has shared or exclusive rights to make decisions in pertaining with the forests and their benefits. Rudito and Melia (2013) argued the Corporate Social Responsibility (CSR) is essentially a requirement for the corporate to initiate interaction with the local community as a form of society as a whole. Forrester (2010) defined a system dynamic as a professional field related to the complexity of a system needed as the basis for effective thinking about the system.

Inam (2015) explicated that within the last twenty years, participatory modeling is the most common method used integrally and adaptively to analyze the complex relationship of natural resource management. However, the model is costly and time consuming as well as requires significant expertise. Any changes in complex natural systems are arranged and linked into a closed causal loop interaction (Forrester, 2009). Forrester (1994) asserted that after the modeling is completed, the logic and accuracy of the computer model simulation is determined by the assumptions as the input of the model.

The complexity of forest ecosystems with the prevailing social system inhibits a scrupulous analysis on the dynamics of the existing forest land cultivation. Nevertheless, the formulation of the problems comprised of: the interrelated factors in association with the forest land cultivation, the produced dynamic model, and the scenarios of dispute resolution policy regarding with the issue.

STUDY AREA AND RESEARCH METHODOLOGY

Study Area

This study was carried out in Kendal with forest area approximately 20,300.58 Ha, and geographically, it is situated between 109°43’28” to 110°24’35” E and 6°51’22” to 7°7’12” S. Administratively, the forest area in Kendal is under the regional governance of Central Java Province as illustrated in Figure 1.

Concept of System Dynamic

Williams and Harris (2005) defined system dynamic as a methodology to study and manage a complex causal loop system. The system or model approach attempts to provide predictions on the possibility of things in the real world system (Forrester, 2009). Purwanto (2005) explained that engineering modeling is a representation of the real world that is presented in the mathematical equations solved analytically or with the assistance of computer device. Forrester (1994) asserted that after the modeling is completed, the logic and accuracy of the output of computer model simulation is determined by the assumptions input into the model. The obstacle in establishing a computer model simulation is to convert the real situation into a model (Forrester, 1992). Mendoza *et al*. (2004) explicated that participative modeling is a general framework that adheres the principle of participatory action where public participation is essential to the success of any management strategy. To ensure a participatory modeling process, hence the modeling environment, formulation and development should be carried out in transparent and understandable to the local community.

Forrester (1992) postulated the stages in creating simulation models including:
1) The relevant system should be described based on the hypothesis on how the system is constructed.
2) Simulation model formulation to interpret the system into the level and equation of dynamics model.
3) Model simulation.
4) Identification of alternative policy.
5) Evaluation of alternative policy.
6) Implementation of the new policy.

Muhammadi *et al*. (2001) explicated that the simulation is defined as an imitation of phenomenon or process behavior. It is aimed to understand specific phenomenon or process, to make analysis and to forecast the behavior of the phenomenon or the process in the future. Jeffer (1998) asserted that to conduct an analysis of the model, there are two categories, namely the analytical model and the simulation model. Manuschevich *et al*. (2016) showed that the policy formulation regarding with conservation areas can be helped by the method of Dyna-CLUE approach to simulate the land-use changes.

System approach by Grant (1998) provides explanation related with the process of conceptualization, measurement, evaluation, and simulation model implementation to identify the causal relationships within a complex system that cannot be detected by other problem solving methods. Forrester and Senge (1980) affirmed that the model validation is a process to build trust and confidence in the usefulness of the model. Coyle (1999) added, the model is in essentially not true, but to assure that the model is close to the truth, the testing is required. Barlas (1996) emphasized that out of the three model validation tests, namely the

Figure 1. Study area

model structure test, model performance test, and model accuracy test, the first one is the most significant validation measure to determine whether the model is accurate or not. According to Arne *et al*. (1996) explicated that powersim is a software which is made on the basis of system dynamic model with a high ability to perform simulation.

Causal Loop Diagram of Land Cultivation

Interaction between the local community and the forest is a complicated system relationship. It can be investigated through the causal loop mechanism that can have either a positive or a negative relationship among the elements (Sterman, 2000). The interaction is illustrated in Figure 2.

System Dynamic Modeling using Powersim studio 10 Software

Facts on the study area indicated that the relationship between the land cultivation and the forest sustainability is a complex one. It is a non-linear interaction that has both positive and negative causal relationship. Based on such relationship, modeling was carried out with the stages as illustrated in Figure 3.

Issues, Problems, and Objectives Identification

To identify issues or problems, objectives and limits is by processing and sorting out the primary and the secondary data associated with and considered essential in the sustainability of the forest resources and environment functions.

Model Conceptualization

The conceptualization of the model was done by using diverse methods such as a box and arrow diagram, causal relationship diagram, stock and flow diagram. It consisted of determining the model formulation, identifying the diagram, performing the quantification and or qualification of model components if it was required.

Modeling

Modeling was done by using powersim Professional Studio 10 software. Simulation is an attempt to imitate the real behavior into a model. The purpose of simulation is to understand the phenomenon of the process, to analyze and to optimize the process behavior that can be used to predict the future. Modeling involves the stage of data and information input into a flow diagram such as Stock, flow, auxiliary or parameters/constants.

1. The collected data presumed to be significant were entered into the Stock-Flow that had been established previously. The data were specifically limited in the range of 2013 to 2015 obtained from Statistics Kendal, *Perum Perhutani Kendal*, the Ministry of Environment and Forestry, and the sub-districts in adjacent to *Perhutani Kendal*.

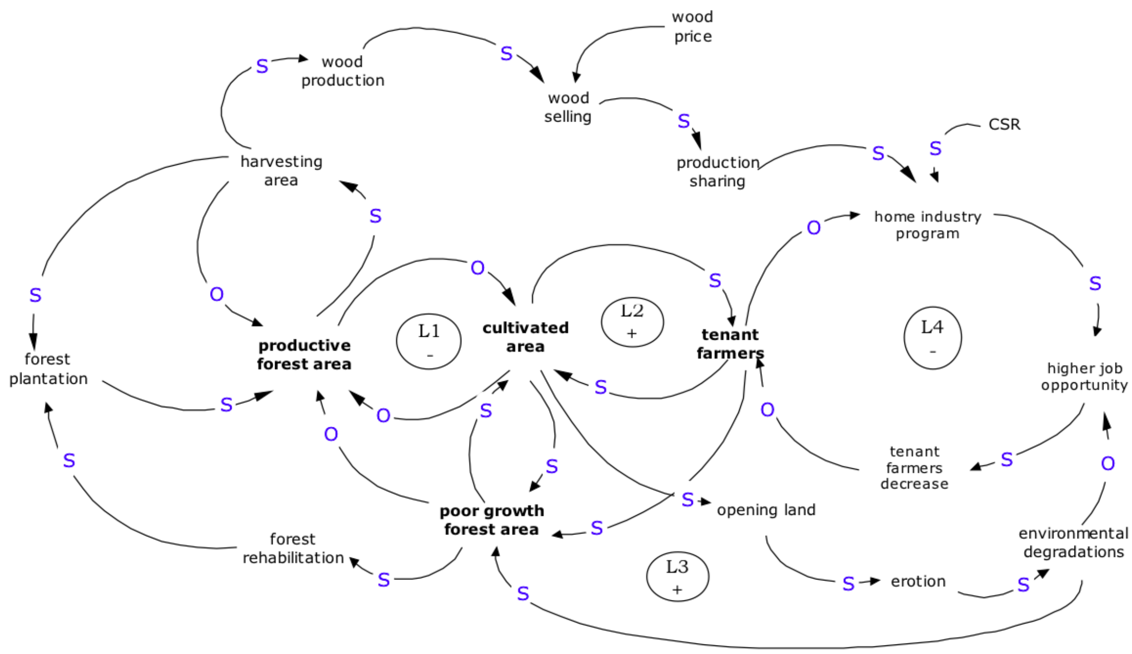

Figure 2. Causal Loop Diagram of Land Cultivation

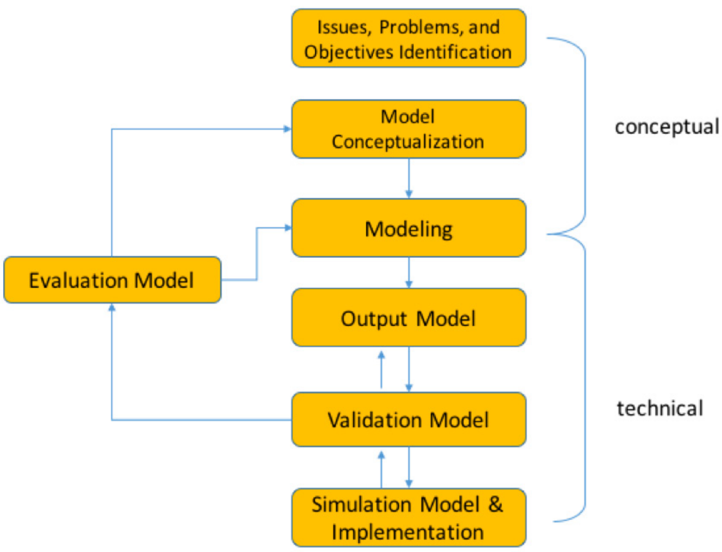

Figure 3. Stages in modeling

2. In Stock, the input was the average data of the last three years and entered merely at the beginning of modeling.
3. In Flow, a simple mathematical equation formulation was employed including multiplication, addition, subtraction or division.
4. Another input data is constant.

Model Validation

The fourth stage was the validation of the model by using Absolute Mean Error (AME) by comparing the performance of the model output with the actual data. The procedure of consistency test used two steps, *first*, by releasing simulation output and then compared it with the visual empirical data behavior patterns. Subsequently, if there was any irregularity, the variable and parameter of model would be fixed based on the investigation on the causes of such irregularity. *Second*, the simulation output that was in accordance with the actual data pattern was statistically tested by using Absolute Means Error (AME) to validate the results.

Absolute Means Error (AME) is a deviation between the average simulation value and the actual value. Acceptable deviation limit is between

5–10%. If AME < 5–10%, the model can be classified as valid. And if AME > 10%, the model must be evaluated. The mathematic formula of AME is as follows:

$$AME = \frac{(Ds - Da)}{Da} x\ 100\% \quad (1)$$

where: Ds : Simulation data
Da : Actual data
AME : Absolute Means Error

RESULTS AND DISCUSSION

Forest land cultivation in Kendal has been practiced for a long time. In fact, it is divided into the legal and illegal cultivation. Based on the generated loop characteristics, the cultivated land area and the number of tenant farmers have interreinforced positive loop relationship. Furthermore, the cultivated land area and the productive forest area have intercorrected negative loop interaction. While the relationship of cultivated land, land clearing, environmental degradation, and poor growth forest area have interreinforced positive loop interaction. On the contrary, the number of tenant farmers and the increase of job opportunity have intercorrected negative loop relationship.

This study aimed to develop a model of forest land cultivation to synergize the local community partnership program in order to prevent the environmental degradation. The objectives of this study included:

1) identifying the interrelated factors in the causal relationship,
2) modeling a forest land cultivation, and
3) conducting model simulation to obtain alternative forest management policies.

Table 1 demonstrates several indicators of the land cultivation, forest rehabilitation, the number of tenant farmers as the input in the modeling.

Business as Usual (BAU)

Figure 4 and Figure 5 illustrate the flowchart and the performance of business as usual model of forest land cultivation. Illegal land area, the number of tenant farmers and the poor growth land area (TBK) has a rising trend. Meanwhile, the area of productive forest is declined. Based on Figure 4, it can be formulated that:

- The sign of problem: Declined productive forest area.
- Problem solution: Reduction of cultivated land and number of tenant farmers.
- Resolution basis: Higher job opportunity for tenant farmers.

Productive forest area, the number of tenant farmers, cultivated land area, and poor growth forest area within the range of simulation years of 2013 to 2015 are presented in Table 2. The table shows that the performance of those four variables has similar pattern with the actual data.

Table 1. Several Indicators of the Land Cultivation

No	Indicator	Unit	Year			Average
			2013	2014	2015	
1	Total of forest area for production	Ha	3643.00	3575.80	3595.50	3604.77
2	Forest area under cultivation	Ha	1625.20	1919.50	2469.30	2004.67
3	Poor growth forest area	Ha	766.10	720.70	726.30	737.70
4	Percentage of forest degraded area (2/3)	%	47.14	37.55	29.41	36.80
5	Productive forest area	Ha	2876.90	2855.10	2869.20	2867.07
6	Percentage of cultivated area (2/1)	%	44.61	53.68	68.68	55.61
7	Cultivated area per tenant	Ha	0.23	0.27	0.35	0.28
8	Tenant farmers	Person	7100	7063	7114	7092
9	Percentage of tenant increasing	%	N	N	N	0.90
10	Percentage of tenant decresing	%	N	N	N	0.52
11	Uncultivated forest area	Ha	2017.80	1656.30	1126.20	1600.10
12	Rehabilitation area	Ha	85.10	108.20	85.40	92.9
13	Percentage of rehabilitation area (12/3)	%	11	15	12	13
14	Deforestation rate in cultivated area	%	N	N	N	0.90
15	Cultivation rate from uncultivated forest area	%	0.011	0.016	0.031	0.018
16	Rate of abandoned cultivation area	%	0.014	0.014	0.014	0.014

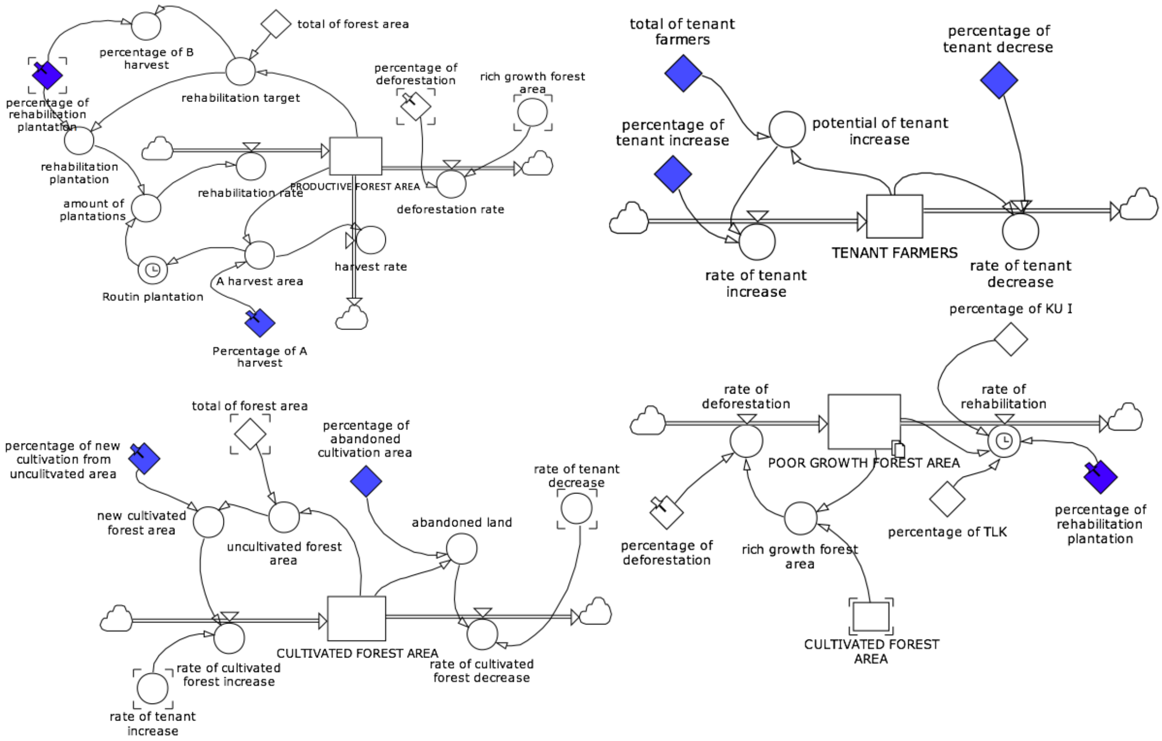

Figure 4. Flow diagram of BAU land cultivation

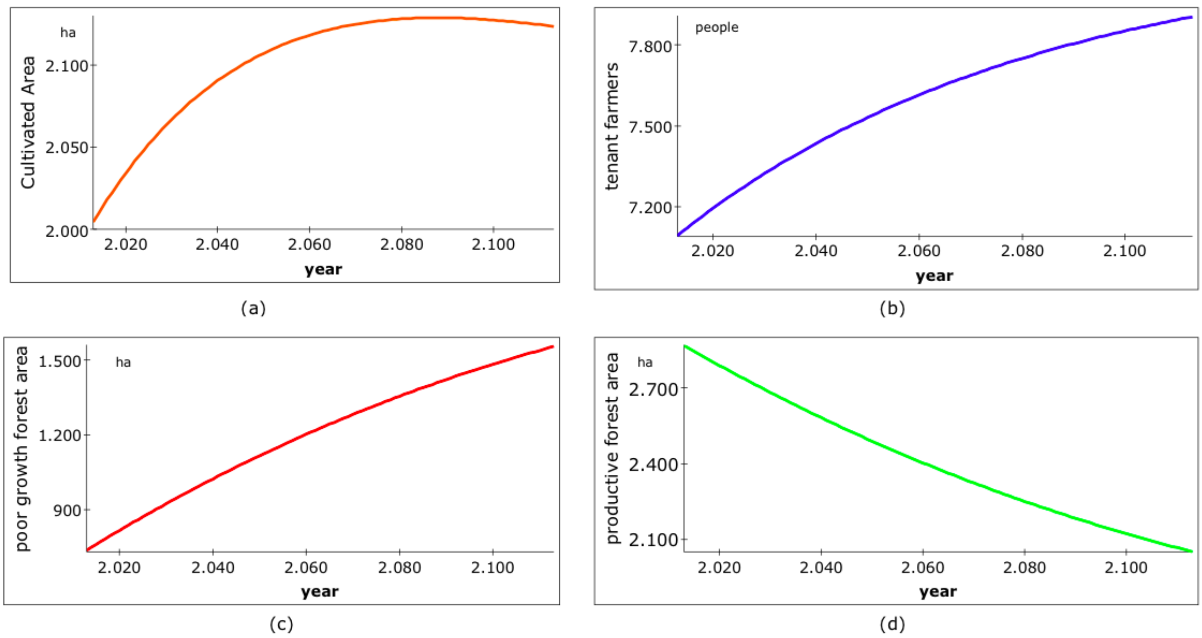

Figure 5. Performance of BAU land cultivation model

Table 2. Business as Usual Performance Model

Year	Productive Forest Area (ha)	Tenant Farmer (Person)	Cultivated Area (ha)	Poor Growth Forest Area (ha)
2013	2867.00	7092.00	2004.67	737.70
2014	2855.60	7107.17	2009.24	749.10
2015	2844.26	7122.12	2013.67	760.44

MODEL VALIDATION

To identify the validity of a model built based on the real condition, the Absolute Means Error (AME) was calculated. The results of AME calculation for the poor growth forest was 1.54%, productive forest area was 0.40%, illegal cultivated land was 0.23%, and the number of tenant farmer was 0.21%. Since the AME value of all indicators was less than 10%, the model can be determined as valid. The detailed calculation of the AME as to which Table 3. Specifically, the AME calculation is presented in Table 3.

The First Scenario of Timber Harvesting Based on Etat and 25% of Production Sharing

The first scenario is the implementation of the timber harvesting policy in accordance with an agreement between Perhutani and forest community (LMDH). Plants were fully harvested in accordance with the cooperation carried out at the age of 60 years. The agreement with LMDH was commenced in 2002, hence based on the agreement, the teak trees will be fully cut off in 2062 as well as the provision of 25% maximum sharing of the production value. Etat is the allowable allocation of harvest at the Perhutani company. The permissible etat is 1.9% of the total productive forest per year. The first scenario is illustrated in flow diagram in Figure 6 and the model performance after the policy of increasing PHBM sharing revenue is illustrated in Figure 7.

Based on Figure 7(a), the performance of illegal land area was divided into two trends. *First*, an increase in cultivated land from 2013 to 2063 amounted to 114.36 ha or a rise of 5.7%. *Second*, a decrease from 2064 to 2105, which is 2062.26 ha of illegal land in 2064 into 1204.87 ha or approximately 41.5% reduction in 2105. Similarly, with the trend of illegal land area, the number of tenant farmers increases from 2013 to 2063 as many as 538 farmers or approximately 7.5%. Subsequently, between 2064 to the end of the simulation year, there is a decrease by 95.4% or 2022 farmers. The trend in the number of tenant farmers is illustrated in Figure 7(b).

Table 3. The AME Values of Validation Testing on Land Cultivation Model

Year	Poor growth forest area		Productive forest area		Cultivated area		Tenant farmer	
	simulation	actual	simulation	actual	simulation	actual	simulation	actual
2013	737.70	766.10	2867.00	2876.90	2004.67	1625.20	7092.00	7100.00
2014	749.10	720.70	2855.60	2855.10	2009.24	1919.50	7107.17	7063.00
2015	760.44	726.30	2844.26	2869.20	2013.67	2469.30	7122.12	7114.00
Sum	2247.24	2213.10	8566.86	8601.20	6027.58	6014.67	21321.29	21277.00
Average	749.08	737.70	2855.62	2867.07	2009.19	2004.67	7107.10	7092.33
AME	1.54	<10%	0.40	<10%	0.23	<10%	0.21	<10%
Conclusion	valid		valid		valid		valid	

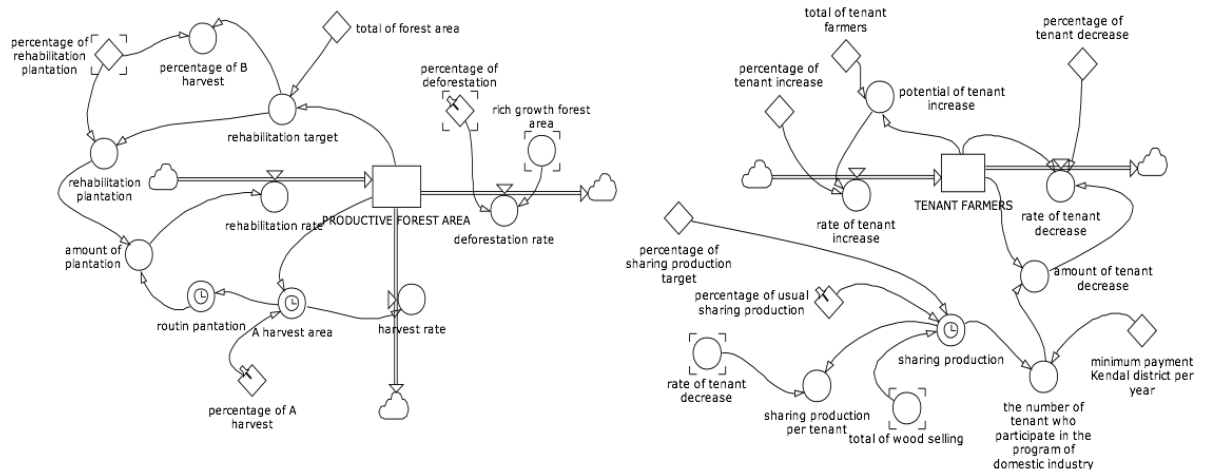

Figure 6. The First Scenario Flow Diagram

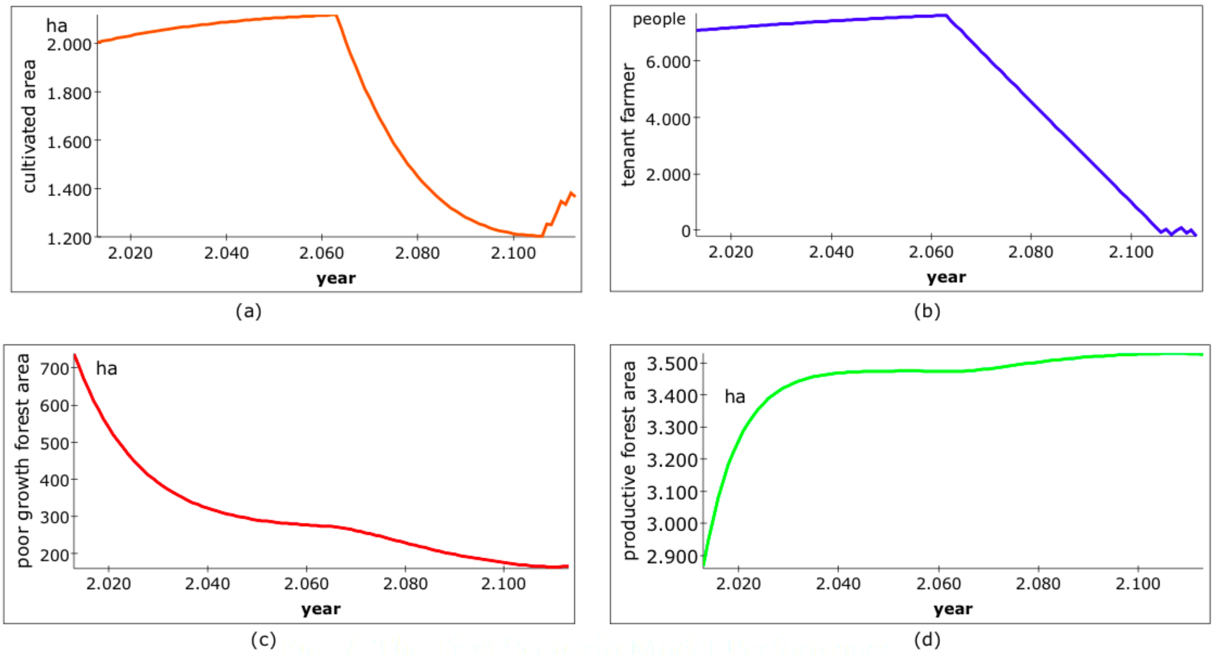

Figure 7. The First Scenario Model Performance

As demonstrated in Figure 7(c) the width of poor growth forest area is declined. In the first year, the forest area is 737.70 ha falls into 274.34 ha in 2063. The trend continues until 2105 with an area of 167.88 ha. Meanwhile, the development of productive forest area as illustrated in Figure 7(d) has a rising trend. In the range of 2013 to 2026, the productive forest area enhances by 18.2% or approximately 520.78 ha. Furthermore, in 2027 until the end of the simulation year, the area of productive forest is relatively stable of 3,400 ha.

The Second Scenario of 25% Production Sharing and 2% CSR

The second scenario policy is the first scenario policy applied simultaneously with CSR policy with a maximum of 2% profit achieved by the corporate. Perhutani get profit of Rp.11.7 billion in 2013. CSR granting can be given of Rp. 235 million in 2017. The flow diagram of the second scenario is illustrated in Figure 8 and the model performance is illustrated in Figure 9. According to Figure 9(a), the rising trend of illegal land area is decreased. The first period is 2018 to 2058. In this time span, the cultivated area declines by 10.75% or approximately 217.17 ha. The second period is in 2058 to 2084. In this second period, illegal land area declines by 39.60% or approximately 713.56 ha. For the period of 2085 until the end of the simulation year, the illegal land area is overshoot or cannot be estimated. It can be identified from the generated graph pattern (Purnomo, 2003). In overall, from the early year to 2084, there is a decline of illegal land area by 45.72 % or approximately 916.61 ha.

In line with the decrease in land area, the number of tenant farmers also declines as illustrated in Figure 9(b). The first period of 2018 to 2058 demonstrates a decline by 14.73% or 1,052 farmers. In the second period of 2058 to 2084, it declines by 97.65% or 5,944 farmers. In the period of 2085 to the end of the simulation year, the number is overshoot or cannot be predicted (Purnomo, 2003). In the period of 2013 to 2084, the number decreases by 97.98% or approximately 6,949 farmers.

Forest area with poor growth is illustrated in Figure 9(c), the declining trend is depicted in which at the early year, the forest area is 737.70 ha and decreases by 75.99% or 177.11 ha. The area is relatively stable until the end of the simulation. On the contrary, the trend of productive forest area endures a rising trend as illustrated in Figure 9(d) to the point of balance. The productive forest area in 2013 to 2037 is significant amounted to 600.53 ha or by 20.94%. After 2037 to the end of the simulation year, the increase of productive forest area is relatively low by 1.7% or approximately 61.6 ha.

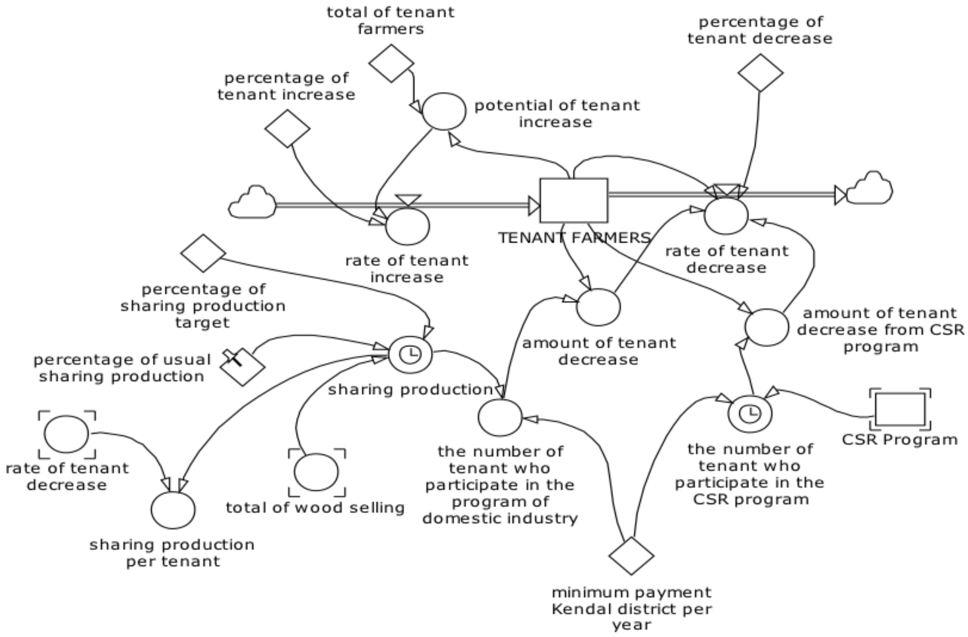

Figure 8. The Second Scenario Flow Diagram

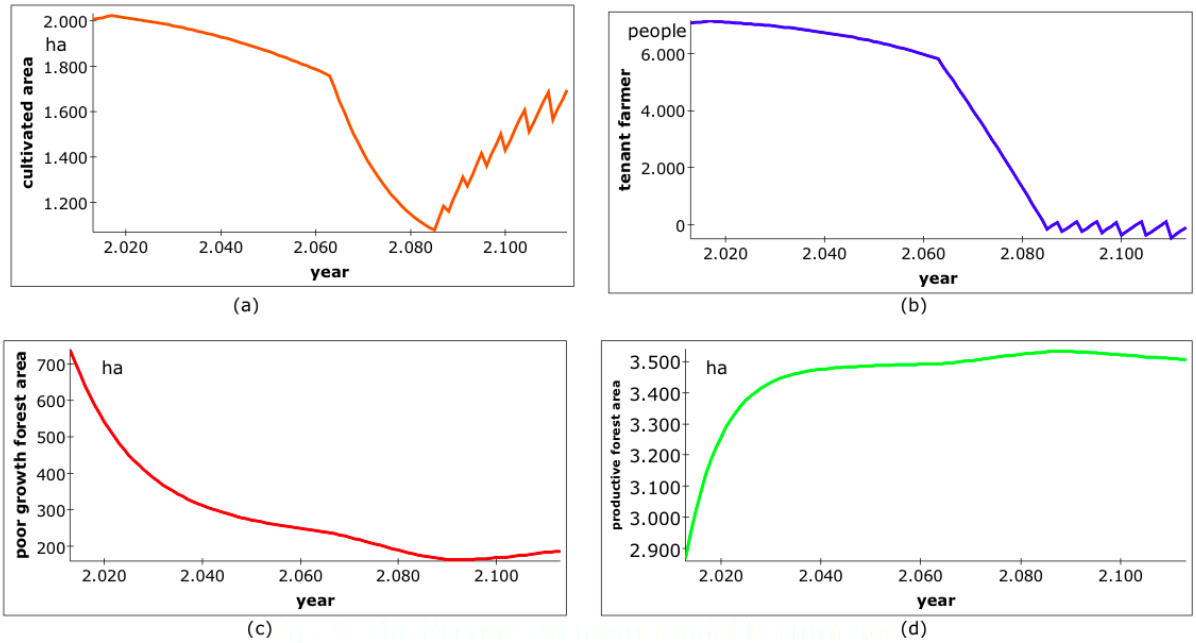

Figure 9. The Second Scenario Model Performance

CONCLUSIONS

This study identified the interrelated factors in pertaining with the issue of illegal cultivation in forest land based on the causal loop diagram. First, the number of tenant farmers. Second, the illegal land area. Third, the poor growth forest area (TBK). Fourth, productive forest area. Fifth, the higher job opportunity for tenant farmers. In accordance with the model generated in this study, both the number of tenant farmers and the illegal land area have a rising trend. Scenario to improve the tenant welfare through the increased productive business based on the partnership from 25% of sharing production that is required on the value of timber trade in 2062 and the fund from 2% Corporate Social Responsibility (CSR) of the profit obtained by Perum Perhutani KPH Kendal implemented in 2017, can inhibit the increase rate of the tenant farmers number and also the illegal land area. Within 67 years, the number of tenant farmers decreases by 97.9% or 7006 farmers. I addition, the illegal land area declines by 916.61 ha or an average of 13.68 ha per year.

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