System Dynamics Model Development for Evaluation of the Moratorium Policy on New Forest and Peatland Concessions under Bilateral Cooperation in Indonesia: Palm Oil Industry Sector Case Study

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Abstract: In this study, we aim to develop a system dynamics model to provide analysis on the impact of the moratorium policy on the new forest and peatland concessions under the reducing emissions from deforestation and forest degradation cooperation in Indonesia's economy and environment. A scenario-based approach was conducted using system dynamics modeling to extrapolate two basic scenarios of with and without the moratorium policy. The results demonstrated that the policy noticeably reduces carbon dioxide emissions from deforestation. However, the reduction is only temporary, and the emission trend under the moratorium policy scenarios would eventually return to the business as usual level. By contrast, Indonesia would face a trade-off between emission reductions and economic growth. Because of the policy implementation, Indonesia should be prepared to weather the economic slowdown. Furthermore, the slowdown effect would last sufficiently long when compared to the policy period.

Keywords: System dynamics, Indonesia moratorium policy, REDD-plus, CO_2 emissions, Palm oil.

1. Introduction

The Kyoto protocol has brought a new policy direction for climate protection using three market-based mechanisms: emission trading, the clean development mechanism, and joint implementation [1]. Since then, "greenhouse gas (GHG) emissions -most prevalently carbon dioxide (CO_2)-became a new commodity." [2]. Countries that bond with the target GHG emissions reductions in the Kyoto protocol can reach a portion of their targets using the three market-based mechanisms, that is, "it does not matter where the emissions are reduced, as long as the emissions are removed from the planet's atmosphere." For instance, they can develop green investments in developing countries to meet their reduction target. Regarding the international carbon market-based mechanisms for climate protection, reducing emissions from deforestation and forest degradation (REDD-plus) is one of the various negotiating tracks set to succeed the Kyoto Protocol. REDD-plus is a new framework which acknowledges the importance of forests in addressing climate change and emphasizes providing financial compensation to participating countries are willing and able to reduce emissions from deforestation [3-4].

With regard to the GHG emissions, Indonesia is recognized as the third largest emitter in the world, of which roughly 85% comes from land use change and forestry, this is largely due to the release of CO_2 emissions from deforestation [5]. However, the Indonesian government is committed to reducing 26% to 41% of GHG emissions relative to the business-as-usual (BAU) level by 2020 [6]. A reduction of 26% may be attained using Indonesia own domestic sources, whereas a reduction of 41% can be completed with support from international partners. In accordance with the commitment, in May 2010, Indonesia and Norway signed a letter of intent for REDD-plus cooperation [7]. Norway intended to provide funds of up to USD $1 billion for forest conservation programs to help significantly reduce deforestation -caused GHG emissions in Indonesia. Under that agreement, Indonesia agreed to enact a 2-year suspension on all new concessions for the conversion of peatland and natural forest. The bilateral agreement finally came into force 1 year later, in May 2011, when the Indonesian president signed Presidential Instruction No.10/2011, which enacted the 2-year suspension (termed the "first phase of moratorium policy (MP-1)") [8-9].

Before the implementation of the MP-I, strong opposition arose from the palm oil industry sector, which was incorporated into the Indonesia Palm Oil Producers Association (GAPKI). They argued that the MP would hamper the industry's plan to double the amount of production by 2020 to meet the growing global demand of palm oil [10]. They also suggested to the Indonesian government that as a developing country, Indonesia must prioritize economic development over the environment. Moreover, Latul and Chatterjee [11] reported concerns that the MP may stymie palm oil production, creating a perception of land scarcity in Indonesia and increasing land prices by 30%–50% over current levels.

Regarding Indonesian palm oil (IPO), the industry is a vital agricultural industry that plays a prominent role in the economic development of Indonesia. Since Indonesia became the largest producer of palm oil in the world, it contributes up to 44% of global palm oil production, a figure that is continually increasing [12]. This industry has always been the biggest and sole non-fossil fuel commodity (the commodities being coal, oil, and gas) of Indonesia in terms of export contribution [13]. It contributes 6% to 7% of Indonesia's gross domestic product (GDP), and approximately 3.7 million people in Indonesia are involved in the industry [14]. However, in addition to the economic advantages, some key issues regarding environmental impacts resulting from the industry exist, specifically in the plantation phase. It relates to the extensive land required to establish the vast monoculture palm oil plantations, most of which are obtained by converting natural forest. As indicated by various documents, these issues include climate change (i.e., plummeting carbon stocks), loss of biodiversity, the extinction of endangered animals, soil erosion, and air, soil, and water pollution [15-16].

Before the MP-1 expires in May 2013, there is debate among stakeholders in Indonesia as a result of the announcement by Indonesia's forestry minister that he will provide a recommendation to the President that the MP-I should be extended [17]. As a result, strong rejection has come not only from industry association that rely on forest conversion and utilization but also from Indonesian House representatives. However, Indonesia's President had decided to extend the MP-I for a further two years, that is until 2015 (termed the "second phase of moratorium policy (MP-2)") [18]. The total time of 4-years is a long enough for suspension on all new concessions, thus, the impacts of this policy must be understood for future critical decisions. In addition,

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answering unresolved questions, such whether this policy is in line with the green economy concept of Indonesia, should be conducted in the context of development that is in favor of economic growth and the environment [19]. Hence, it is necessary to conduct an analysis that clarifies the impact of the moratorium policy (termed the "MP ", covers MP-1 and MP-2) by focusing on one economic sector that relies on forest conversion and use for its business activities. The dynamic problems presented previously that cover environmental concerns and economic activities can be modeled using the system dynamics (SD) approach. This study was undertaken to develop a SD model that clarifies the impact of the MP on the environment and the economy of Indonesia using a case study of the palm oil industry sector.

2. Method and Modeling Process

The development of the model of this study follows the SD methodology, provided especially in Forrester [20], Sterman [21], and Ford [22]. Fig. 1 depicts the framework of this study that consists of the input, process, output, and feedback diagrams of the modeling process, including the model structure. Owing to the bilateral agreement linking the GHG emissions reduction with financial incentives, we first determine the sustainability indicators from environmental and economic perspectives that are relevant to the theme of study. To evaluate the MP, CO_2 emissions was selected as an environmental indicator that measures the effectiveness of MP implementation, and the CPO yield that is produced by the IPO was selected as the economic indicator for obtaining an overview of the forest use for economic purposes. We then designed two basic scenarios, the BAU scenario and the MP scenario. The BAU scenario is our descriptive scenario in the absence of the MP, whereas the MP scenario is a descriptive scenario of the MP implementation. The scenarios were subsequently formalized into the SD model. We first built the BAU model, which is a formalization of the description of the interrelationships among major variables in real systems (Fig. 2). The BAU model is divided into sub-models of palm oil demand, palm oil plantation, and impact. When the BAU model is imposed on by the MP sub-model, it becomes an MP model. Each sub-model has main outputs that connect the relationship between sub-models. After the model is developed and it has successfully passed the model validation procedures, the model was used for experimentation (i.e., through simulation).

2.1 Model Conceptualization

2.1.1 Problem Definition

Because palm oil can be used as a versatile vegetable oil for a range of edible and non-edible products, including biofuel, it is the most highly demanded vegetable oil in the world. Thus, the expansion of palm oil plantations has been inevitable to meet the high demand of palm oil [23]. Rising demand for palm oil triggers investment in the palm oil industry sector by establishing new palm oil plantations (i.e., expansion) to increase production to meet the demand. The demand of palm oil and land use change (LUC) is like two sides of the coin that cannot be separated. Hence, the key variables that we consider to be important variables that may depict the initial characterization of the problem are the global palm oil (GPO) demand and the Indonesia palm oil plantation area (IPOPA).

Figure 2 shows the historical data for the two key variables [24-27], indicating that GPO demand in 2010 more than doubled compared to 2001, that is, from 28.1×10^6 megagram (Mg) in 2001 to 52.1×10^6 Mg in 2010 for an average growth rate of 7.1% per year. Similarly, IPOPA increased from 4.7×10^6 hectare (ha) in 2001 to 8.4×10^6 ha in 2010 for an average growth rate of 6.8% per year. Thus, the data confirm that a relationship exists between GPO demand and IPOPA, that is, the GPO demand is set to determine the LUC in Indonesia related to palm oil plantation expansion. Furthermore, considering the analysis of the United States Department Agriculture (USDA), reliance on the Indonesian Palm Oil (IPO) production to meet future GPO demand cannot be avoided. Hence, both GPO demand and IPOPA trends are predicted to continue growing for the future [28].

2.1.2 System Description

Understanding the impacts of the MP on the economy and environment of Indonesia lies in the relationship between the supply–demand system of palm oil. The demand side covers palm oil demand on the international level (GPO demand), national level (IPO demand), and the total land required for it. The supply side covers the fulfillment of required land for the IPO industry sector in order to meet the IPO demand.

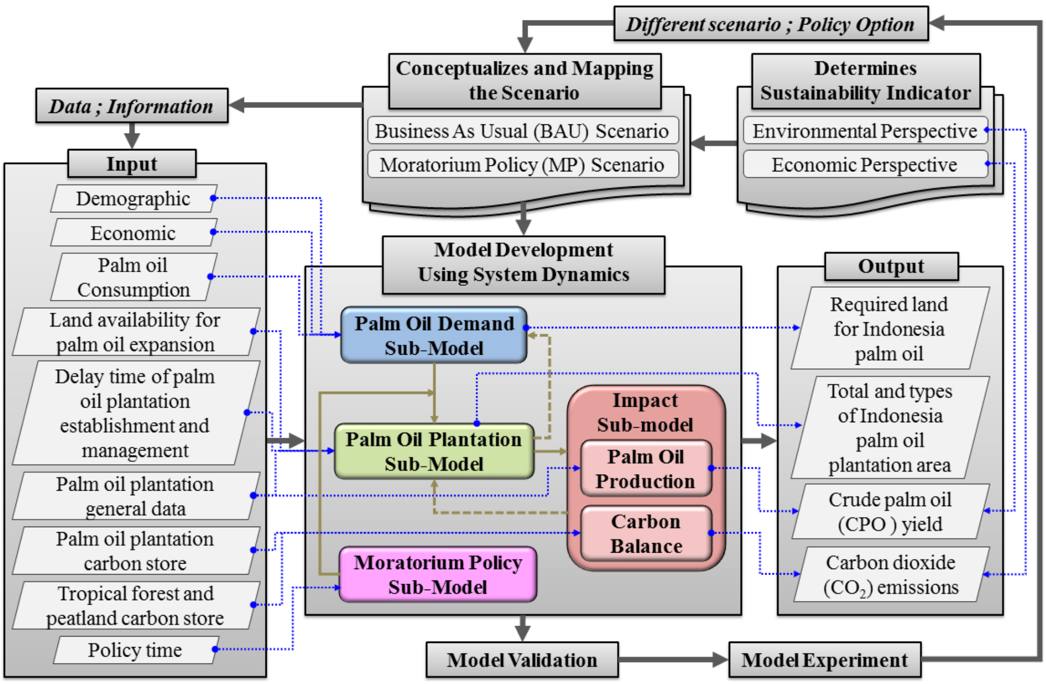

Figure 1. The study framework.

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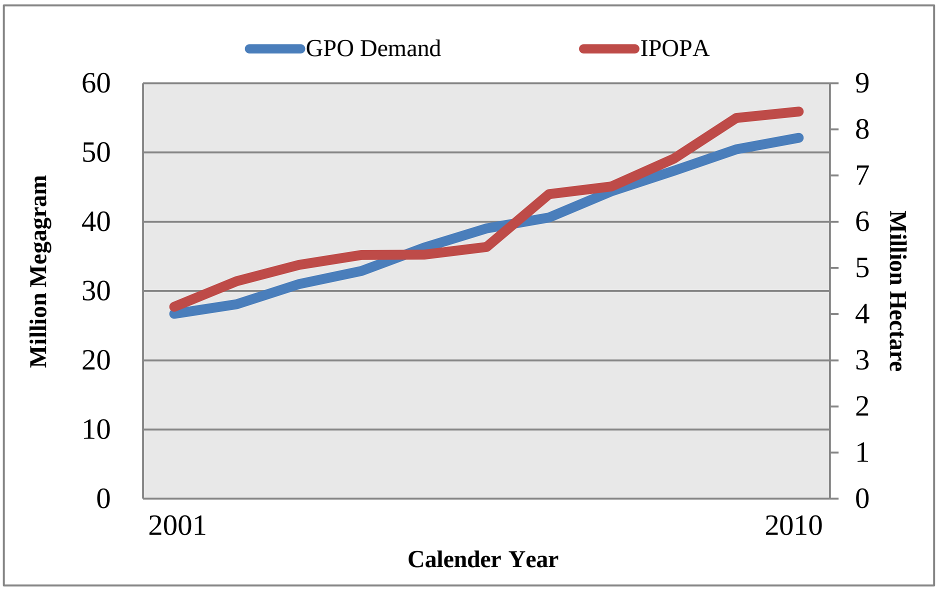

Figure 2. Historical global palm oil demand and Indonesia palm oil plantation area for 2001-2010.

Demographic change and economic growth are commonly used as the main factors affecting demand in all sectors. With regard to the GPO demand, Corley argued that future GPO demand will increase because of a growing world population and consumption per capita [29]. We adopted the Corley model, adding GDP growth and personal income as other variables that are assumed to determine palm oil consumption (POC) per capita.

The variables in the real system used to describe the system being studied can be identified and determined based on the key variables, current theories, and assumptions previously discussed. Figure 3 shows the interrelationships among selected variables of the real system that comprise the qualitative structure of the system being studied. The descriptions of the structural relationships are as follows.

(a) The world demographic and economic situations, which are represented by growing population and GDP, respectively, create the GPO demand. The GPO demand is determined using global population and the POC per capita. The POC per capita is influenced by personal income, which is measured using GDP per capita. Personal income is assumed to affect or positively correlated with POC per capita.

(b) The GPO demand automatically affects the IPO demand that is estimated using the IPO's market share in the GPO market. Owing to the law of supply and demand that is naturally applied in the business world, the IPO industry is assumed to always try to meet the IPO demand by expanding their plantation area to increase crude palm oil (CPO) production. The expansion of the plantation area is eventually added to the total IPOPA. Thus, total IPOPA is supply-side or is a variable that balances the land use demand.

(c) Most palm oil plantations in Indonesia are located in former tropical forest, and the conversion of tropical forests to palm oil plantations continues to occur [30]. Thus, the establishment of new plantation areas is assumed to be in tropical forests and peatland areas. The new plantation establishment releases carbon to the atmosphere (carbon debt). In contrast, the growth of palm oil crops in the plantation also absorbs carbon from the atmosphere (carbon repayment).

The SD model that is built in this study limits the production process of pal oil only in the plantation phase. Because the approach of the REDD-plus is to address the GHG emissions through forest conservation programs, limiting the production processes in the plantation phase is sufficient to gain insight and understanding about the policy intervention.

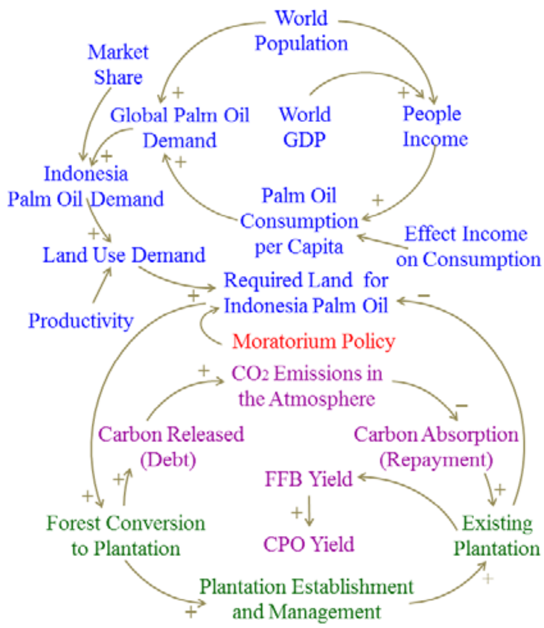

Figure 3. Structural relationships among system variables being studied.

2.1.3 Moratorium Policy Scenario

The implications of the MP implementation were assumed ideally to be extreme circumstances (e.g., no palm oil plantation expansion occurs during the MP implementation) and based on actual situations that have occurred during the implementation of the MP-1. We used three scenarios for the MP implementation implications as follows.

1. The MP-1 suspends palm oil plantation expansion for 2 years from 2011, and the expansion continues after the MP expires in 2013 (ideal circumstance; MP-1 scenario).
2. The MP-2 suspends palm oil plantation expansion for 4 years from 2011, and the expansion continues after the MP expires in 2015 (ideal circumstance; MP-2 scenario).
3. The palm oil plantation expansion continues during the 4 year MP implementation, but at lower rates than those in the BAU scenario (actual situation; MP-3 scenario).

The actual situation related to MP implementation (MP-3 scenario) refers to REDD-Monitor [31], it has reported that the deforestation in Indonesia is continuing despite the implementation of the MP-I. It is mainly caused by forest concessions that were issued before the MP was signed. In addition, law enforcement is not effective. For instance, the Indonesian State Audit Board has revealed that one palm oil company conducted land clearing operations without a license from the Indonesian government.

2.2 Model Formulation

The SD stock variables in Figure 4 are shown as rectangular boxes that represent the accumulation of changes in the system due to connected flows. The flow variables that are shown like valves (double arrow and circle) represent the rate of change in the stock variables by adding or subtracting the values (i.e., inflows and outflows, respectively). The information link variables or connectors (a single line) represent the relationship among variables within the system/model. Four subsystems corresponding to the model conceptualization and scenarios are built and discussed in the following sections.

2.2.1 Palm Oil Demand Sub-Model

The palm oil demand sub-model (Figure 4, blue color) primarily describes the extrapolation of future growth of GPO demand, including the required land for the demand, as described in Section 2.1.2, point A and B for the qualitative model. See Table 1: Items 1 to 11 for the quantitative model. World population growth and GDP are perceived as the main drivers increasing the demand of the GPO. The effect of personal income on POC per capita was estimated using regression analysis based on historical data from 2001 to 2010 (Table 1: Item 7). Whereas for the actual required land to meet the demand for the IPO is obtained by considering all existing palm oil plantations (Existing IPOPA) in Indonesia.

2.2.2 Palm Oil Plantation Sub-Model

The palm oil plantation sub-model (Figure 4, green color) depicts the establishment and management processes of the palm oil plantation, split into five stocks. One stock is used to record the land availability that specifically fo palm oil expansion. The other four stocks (i.e., new, immature, mature, and unproductive IPOPAs) are used to track the plantation area types, describing the stock of the plantation and transitioning between stages based on their age. The management of a palm oil plantation is assumed to be a cyclical and repeating pattern: The palm oil crop is replanted when the crops in the mature plantations become unproductive, and they then repeat the stages of the plantation management process. All equations inside the plantation sub-model are listed in Table 1: Items 12 to 22.

2.2.3 Impact Sub-Model

There are two models inside the impact sub-model (Figure 4, maroon color), which are the carbon balance and palm oil production models. The amount of carbon emissions balanced between carbon debt and carbon repayment was assumed completely oxidized into CO_2 (i.e., multiplied by Molecular weight ratio of CO_2 to carbon). Carbon debt is carbon that is released to the atmosphere as a result of the IPOPA establishment, calculated using the stock of new IPOPA. Carbon repayment is carbon that is absorbed by the palm oil crops in the plantation, calculated using the stocks of immature and mature IPOPAs. The impact sub-model for CO_2 emissions of this study considers only the carbon balance as a result of the palm oil plantation expansion in and after 2010. Thus, immature and mature IPOPAs that absorb carbon are also from plantations established in and after 2010. The CPO yield was calculated based on the stock of mature IPOPA based on number of mature palm oil crops, number of fresh fruit bunches (FFBs) yield per palm crop, and number of FFBs required to produce one ton of CPO (i.e. the "oil extraction ratio (OER)"). The equations for the impact sub-models are listed in Table 1: Items 23 to 29 for the carbon balance and Items 30 to 32 for palm oil production.

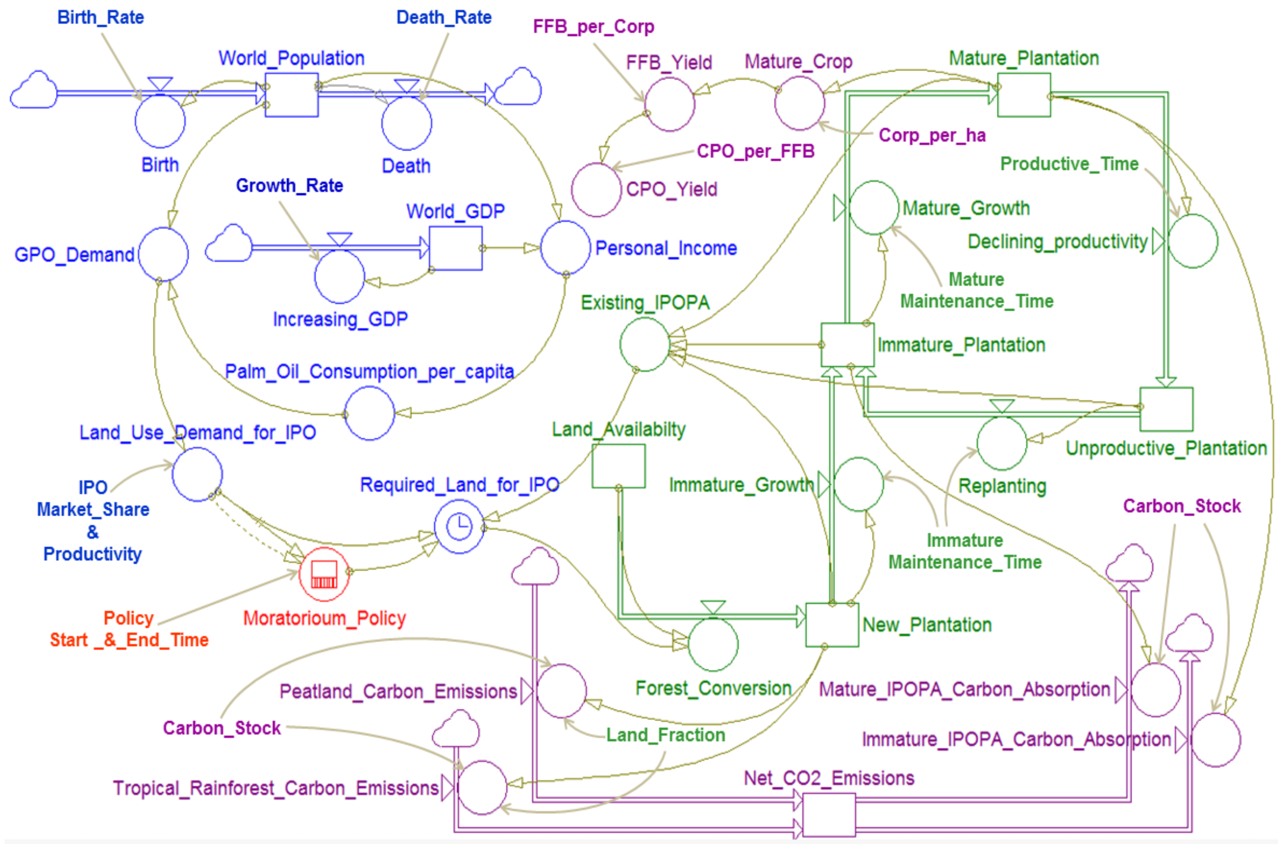

Figure 4. System dynamics model of this study.

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Table 1. SD formulas.

Item	Variable	Equation
1	World population (t)	= World population in 2010 + $\int_{2010}^{t}$ Births(s) ds $- \int_{2010}^{t}$ Deaths(s) ds
2	Births (t)	= World population(t) · Crude birth rate
3	Deaths (t)	= World population(t) · Crude death rate
4	World GDP (t)	= GDP in 2010 + $\int_{2010}^{t}$ Increasing GDP(s) ds
5	Increasing GDP (t)	= World GDP(t) · GDP growth rate
6	Personal income (t)	= World GDP(t) / World population(t)
7	Effect of personal income (t) on POC per capita (t)	= 0.001 + [7.08×10^{-7} · Personal income(t)]
8	GPO demand (t)	= World population(t) · POC per capita(t)
9	IPO demand (t)	= GPO demand(t) · IPO market share
10	Land use demand for IPO (t)	= IPO demand (t) / IPO productivity
11	Required land for IPO (t)	= Land use demand for IPO(t) − Total IPOPA(t)
12	Land availability for IPOexpansion (t)	= Potential land in 2010 $- \int_{2010}^{t}$ Forest conversion to plantation(s) ds
13	Forest conversion to plantation (t)	= Required land for IPO(t) / Land preparation time
14	New IPOPA (t)	= New IPOPA in 2010 $+ \int_{2010}^{t}$ Forest conversion to plantation(s) ds $- \int_{2010}^{t}$ New to immature growth(s) ds
15	New to immature growth (t)	= New IPOPA(t) / Immature maintenance time
16	Immature IPOPA (t)	= Immature IPOPA in 2010 $+ \int_{2010}^{t}$ New to immature growth(s) ds $- \int_{2010}^{t}$ Immature to mature growth(s) ds $+ \int_{2010}^{t}$ Replanting(s) ds
17	Immature to mature growth (t)	= Immature IPOPA(t) / Mature maintenance time
18	Mature IPOPA (t)	= Mature IPOPA in 2010 $+ \int_{2010}^{t}$ Immature to mature growth(s) ds $- \int_{2010}^{t}$ Declining productivity(s) ds
19	Declining productivity (t)	= Mature IPOPA (t) / Productive time
20	Unproductive IPOPA (t)	= Unproductive IPOPA in 2010 $+ \int_{2010}^{t}$ Declining productivity(s) ds $- \int_{2010}^{t}$ Replanting(s) ds
21	Replanting (t)	= Unproductive IPOPA (t) / Mature maintenance time
22	Existing IPOPA (t)	= ∑ IPOPA Type = New IPOPA(t) + Immature IPOPA(t) + Mature IPOPA(t) + Unproductive IPOPA(t)
23	Carbon balance (t)	= Carbon emission in 2010 $+ \int_{2010}^{t}$ Peatland carbon emissions(s) ds $+ \int_{2010}^{t}$ Tropical rainforest carbon emissions(s) ds $- \int_{2010}^{t}$ Mature IPOPA carbon absorption(s) ds $+ \int_{2010}^{t}$ Immature IPOPA carbon absorption(s) ds
24	Net CO_2 emissions (t)	= Carbon balance (t) · Molecular weight ratio of CO_2 to carbon
25	Peatland carbon emission (t)	= New IPOPA(t) · Land fraction for IPOPA · Peatland carbon stocks
26	Tropical rainforest (TR) carbon emission (t)	= New IPOPA(t) · (1 − Land fraction for IPOPA) · (TR above-ground biomass + TR below-ground biomass) · TR carbon fraction
27	TR below-ground biomass	= TR above-ground biomass · TR ratio below to above grounds biomass
28	Mature IPOPA carbon absorption (t)	= IF(Mature IPOPA(t) > Mature area 2010, [Mature IPOPA(t) −Mature area 2010] · IPOPA carbon stock accumulation in biomass, 0)
29	Immature IPOPA carbon absorption (t)	= IF(Mature IPOPA(t) > Immature area 2010, [Immature IPOPA(t) −Immature area 2010] · IPOPA carbon stock in biomass after 1 year growth, 0)
30	CPO yield (t)	= FFB yield(t) · OER
31	FFB yield (t)	= Mature crop(t) · FFB per palm oil crop
32	Mature crop (t)	= Mature IPOPA(t) · Palm oil crop number
33	Moratorium policy for MP-1 or MP-2 scenarios(t)	= STEP (Land use demand for IPO(t), Policy end time)
34	Required land for IPO (t) for MP-1 or MP-2 scenarios	= IF(TIME < Policy start time, Land use demand for IPO(t)−Total IPOPA(t), IF(Moratorium policy(t) > Total IPOPA(t), Moratorium policy(t) − Total IPOPA(t), 0))
35	Moratorium policy for MP-3 scenarios (t)	= DELAYMTR(Land use demand for IPO 1, Policy end time - Policy start time,1)
36	Required land for IPO (t) for MP-3 scenarios	= IF(TIME<Policy start time, Land use demand for IPO(t)−Total IPOPA(t), IF(TIME<Policy end time, Moratorioum policy(t)−Total IPOPA(t), Land use demand for IPO(t)−Total IPOPA(t))

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2.2.4 Moratorium Policy Sub-Model

As previously described (Section 2.1.3), the MP is perceived as a variable that suspends or reduces forest conversion to palm oil plantations. The MP sub-model (Figure 4, rose color) is placed between the demand sub-model and the palm oil plantation sub-model, that is, between the variables of the total land use demand for IPO and the required land for IPO. For the MP-1 and MP-2 scenarios, the MP that is perceived as a variable that suspends the forest conversion can be explained as follows.

- If the land use demand for the IPO variable is perceived as mass flows through the MP variable, the MP variable can be seen as a process that captures and eliminates the mass flows for 2 years for the MP-1 (2011–2013) and for 4 years for the MP-2 (2011–2015), modeled using the STEP function (Table 1: Item 33).
- After the MP expires, it returns to the normal condition. That is, the MP variable transfers the mass flows into the required land for the IPO variable for the subsequent calculation. The formulation of the required land for the IPO variable for this scenario was modeled using the arithmetic IF function (Table 1: Item 34).

For the MP-3 scenario, the MP is perceived as a variable that reduces the forest conversion was modeled using the DelayMtr functions. Using this function, the MP-3 variable could be perceived as a process that captures the mass flows through a delay process. Thus, the material from the land use demand for the IPO variable undergoes a delay process inside the MP-3 variable, with an average delay time of 4 years (the validity period of the MP-I and MP-II). The distribution of the output value for the delay was assumed to be a first-order exponential material delay. After the MP expires, it returns to the normal condition; that is, the mass flows from the land use demand for the IPO flows directly into the required land for the IPO. The equations for the MP-3 scenario can be seen in Table 1: Items 35 and 36.

2.2.5 Data and Simulation

We collected the required data/information from several online databases, textbooks, and papers in scientific journals or proceedings. For the statistical data mainly obtained from the World Bank, the USDA, and the Ministry of Agriculture Republic Indonesia (MAORI) databases, we used historical data for each variable over the 10 years from 2001 to 2010. All input data were used as a base for simulating the model listed in Table 2. We used several input data for our assumptions. For the initial conditions of the system (in 2010), the new IPOPA, unproductive IPOPA, and net CO_2 emissions were set to 0. This is mainly because there is no available data and setup for modeling purposes. After the data were determined and inputted, the simulation was conducted. At first, the model simulated the BAU scenario to identify the extrapolation future situation without the implementation of the MP. The BAU scenario then was imposed by the MP (by adding the MP sub-model) to become the MP scenarios. The simulation was run for a 10-year span from 2010 to 2020. This time horizon was deemed sufficient to depict the problem and to see the impacts.

3. Model Validation

The model validation procedures are eventually intended to build confidence that the model is useful in order to enhance our insight and understanding relative to the themes being studied. To do so, historical behavior reproduction test were conducted. For this test, we focused on the key variables (GPO demand and total IPOPA). The historical data series of both variables from 2001 to 2010 (Figure 1) was used to verify the model in extrapolating the trend. For this testing, the initial condition of the model was set at 2001 because the simulation started in 2001 and ended in 2010. The other parameters were set as fixed for the base run. The mean absolute percent error (MAPE) was used for assessing the behavior reproduction of the model. Fig. 5 shows a comparison of the data between the model output and the actual GPO demand data (Figure 5.a) and total IPOPA (Figure 5.b) in a scatter chart. The MAPE of GPO demand and total IPOPA are 4.6% and 4%, respectively. These numbers are under 10%, indicating that the agreement between the historical data and the simulation results was reasonable, because the model was able to reproduce the real system.

Table 2. Input data for model simulation.

No.	Variable	Value	Data Source
1	World population 2010	6,894,377,794 people	
2	Crude birth rate	20 per 1,000 people	
3	Crude death rate	8 per 1,000 people	[32-33]
4	World GDP 2010	63,135,994,837,272.7USD	
5	GDP growth rate	7.1%	
6	IPO market share	53%	[34]
7	IPO productivity	3.1 Mg ha^{-1}	[27]
8	Land preparation time	1 year	
9	Immature maintenance time	1 year	[35]
10	Mature maintenance time	1.75 years	
11	Productive time	22 years	[36]
12	Potential land 2010	45,846,329 ha	[37]
13	Immature IPOPA 2010	1,799,663ha	[27-28]
14	Mature IPOPA 2010	6,024,960 ha	
15	Land fraction for IPOPA	14% (on peatland area)	[38]
16	Peatland carbon stocks	1450 Mg per ha	[39]
17	Molecular weight ratio of CO_2 to carbon	44/12	
18	TR above-ground biomass	350 Mg dry matter ha^{-1}	
19	TR ratio below to above grounds biomass	0.73 Mg root d.m. (Mg shoot d.m.)$^{-1}$	[40]
20	Carbon fraction of aboveground biomass	0.74 Mg C (Mg d.m.)$^{-1}$	
21	IPOPA carbon stock in biomass after 1 year growth	5 Mg ha^{-1}	
22	IPOPA carbon stock accumulation in biomass	5 Mg ha^{-1} $year^{-1}$	[41]
23	Palm oil crop number	130 crops ha^{-1}	[35]
24	FFB per palm oil crop	0.140 Mg $year^{-1}$	[42]
25	OER	0.218 Mg CPO (Mg FFB.)$^{-1}$	[43]
26	Policy start time for the MP-1, MP-2 and MP-3 scenarios	2011	
27	Policy end time for the MP-1 scenario	2013	[9]
28	Policy end time for the MP-2 and MP-3 scenarios	2015	[18]

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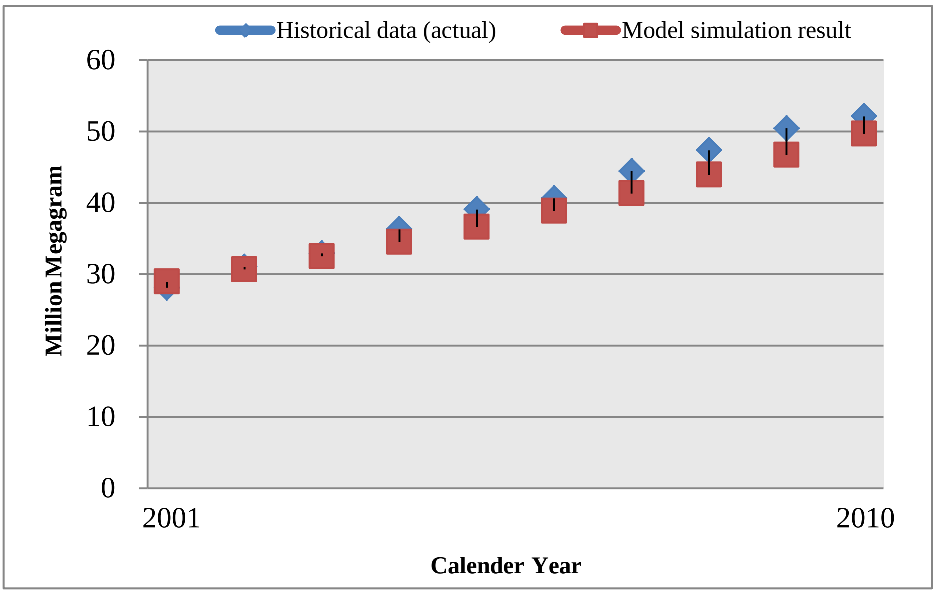
a. Historical data versus projection for global palm oil demand



b. Historical data versus projection for Indonesia palm oil plantation area.

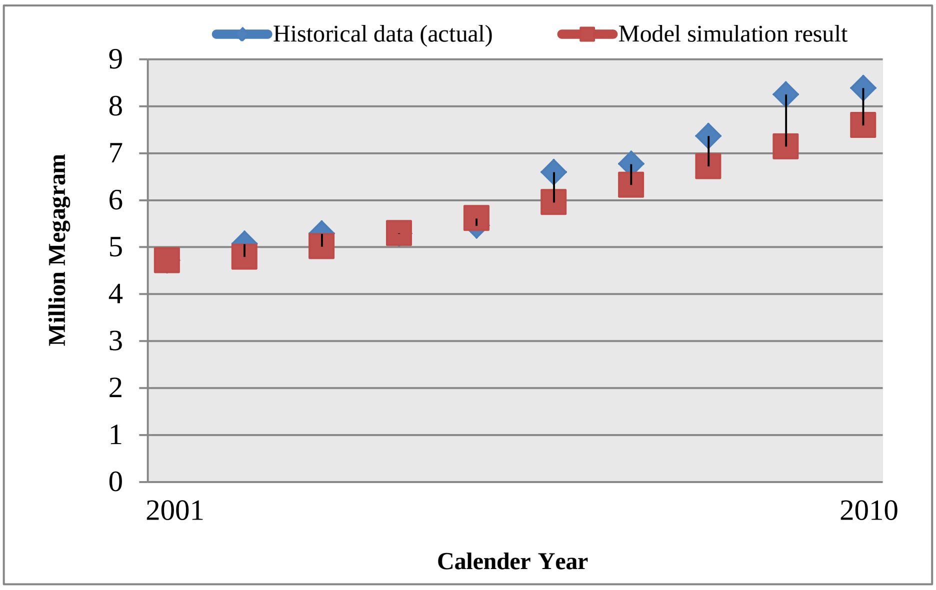


Figure 5. The simulation result of model validation.

4. Evaluation of Policy Options

4.1 Forest conversion to palm oil plantation

The model extrapolates that the total GPO demand in 2020 is projected to reach 98. 1×10^6 Mg, whereas the total IPO demand is estimated to be approximately 52×10^6 Mg in 2020. According to such a level of demand, the total plantation area that ideally should be owned by the IPO industry by 2020 to meet the demand is approximately 15.7×10^6 ha. Thus, the total required land for the IPO to meet the demand is predicted to reach 8.2×10^6 ha during 2010–2020. Under the BAU scenario, the conversion of forest to plantations gradually increases in line with the demand at a rate of 0.74×10^6 ha annually. Under the MP scenarios, the forest conversion to plantation grows exponentially at first, and is then interrupted by the MP implementation. Thereafter, the forest conversion to plantations will shoot up after the MP period expired, followed by an exponential decline until reaching the BAU level. A peak of forest conversion followed by its exponential decline might be understood as follows: After the MP expires, the IPO industry tries to repay their lag in meeting the demand. They then increase their production capacity by boosting the expansion to try to meet the demand. Hence, the annual rate of forest conversion under MP scenarios will be higher than the BAU scenario, it reaches 0.79×10^6, 0.85×10^6, and 0.8×10^6 ha for MP-1, MP-2, and MP-3 scenarios, respectively. After a disturbance of the MP implementation, the rate of forest conversion to palm oil plantations under all MP scenarios returns to an equilibrium condition (i.e., balance between supply and demand); in this case, this is the BAU scenario.

4.2 CO_2 emissions

Because of IPO industry expansion, there is a substantial increase in CO_2 emissions for all scenarios (Fig. 6.a). Under the BAU scenario, the model predicted a carbon debt as a result of the forest conversion to palm oil plantations during 2010-2020 is approximately 2.5×10^9 Mg, whereas the carbon repayment as a result of the growth of palm oil crops in the plantation is approximately 1.2×10^8 Mg. Thus, the total net CO_2 emission that cumulatively balances between carbon debt and carbon repayment multiplied by molecular weight ratio of CO_2 to carbon

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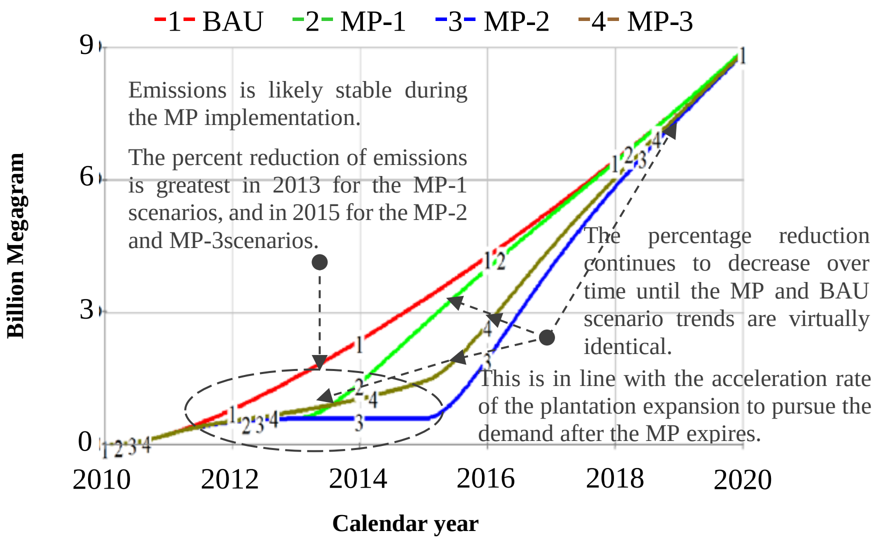
(44/12; table 2 no.17) during 2010–2020 reaches nearly 8.8×10^9 Mg. In contrast, Fig. 6.a shows that the MP implementation positively impacts CO_2 emissions reduction. CO_2 emissions are likely stable during the MP implementation; however, in the end, the trends are virtually identical. The impact of the MP on the reduction of CO_2 emissions by the year 2020 is projected to reach 2.1×10^9, 9.7×10^9, and 2 7×10^9 Mg for M P-1, MP-2, and MP-3 scenarios, respectively. The percent reduction of CO_2 emissions is greatest in 2013 for the MP-1, and in 2015 for the MP-2 and MP-3 scenarios; these are approximately 60%, 81%, and 58% for MP-1, MP-2, and MP-3 scenarios, respectively, compared with the BAU scenario. However, the percentage reduction then continues to decrease over time until the emission level under the MP scenarios return to the level of the BAU scenario. This is in line with the acceleration rate of the plantation expansion to try to meet palm oil demand after the MP expires. Thus, the MP on new forest concessions, which is only temporary (i.e., 2 years for MP-1 and 4 years for MP-2), is able to reduce CO_2 emissions, which are temporary as well.

Focusing only on the MP may not seem to have a significant impact on environmental amelioration for the long term. The model has demonstrated that the emission trend under the MP scenarios eventually returns to the BAU level. Hence, further strategy and policy instruments that are as a continuation of the MP are absolutely necessary. However, the MP can be an initial measure or a springboard for mitigating GHG emissions from deforestation and forest degradation. The time interval during the MP implementation can be used for the preparation of further policy formulations, including the facilities that are required. For instance, if an effective degraded land database is created, future palm oil plantation expansions will be placed on the correct land. By placing the new concessions of palm oil plantations on the degraded land, Indonesia receives both economic and environmental (i.e., reforestation) benefits.

4.3 Crude Palm Oil Yield

Assuming the required land to meet the demand is actually executed over time by the IPO industry sector, the IPO industry is projected to have a mature plantation area of 11.9×10^6 ha by 2020, and will be able to produce 47×10^6 Mg CPO. Fig. 6.b shows the comparison between the CPO yield for the BAU and MP scenarios. The MP has a negative impact on the IPO industry sector, because it hampers the increase of the IPO industry's production capacity in line with the increasing demand. However, the IPO industry will eventually be able to smoothly increase their production capacity to match the BAU level. The IPO industry

a. CO_2 emissions.



b. CPO yield.

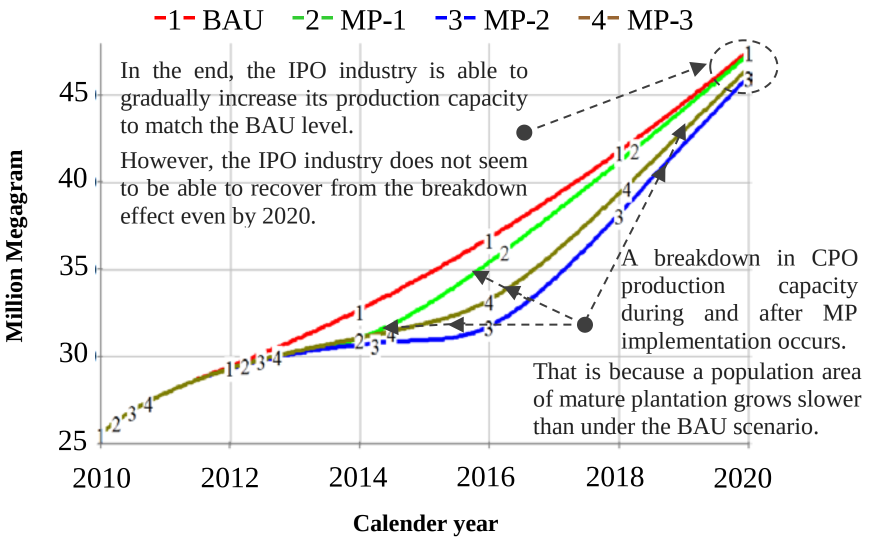


Figure 6. The simulation result of CO_2 emissions and crude palm oil yield over time from 2010 to 2020 under the BAU and MP scenarios.

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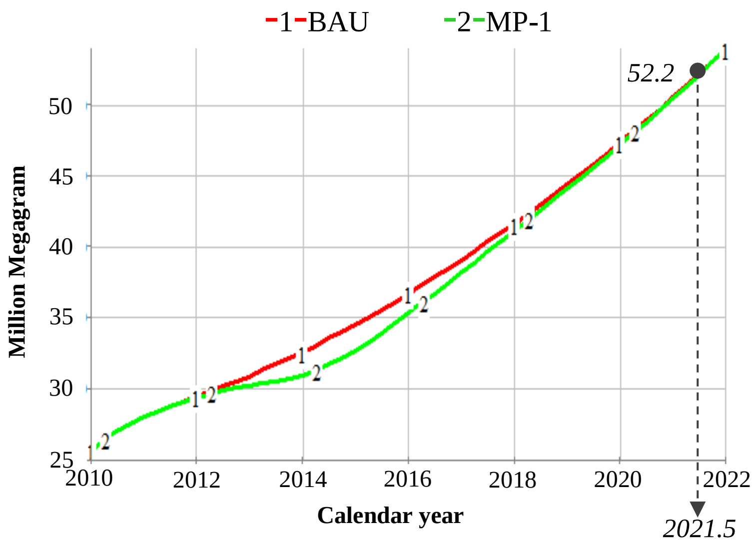
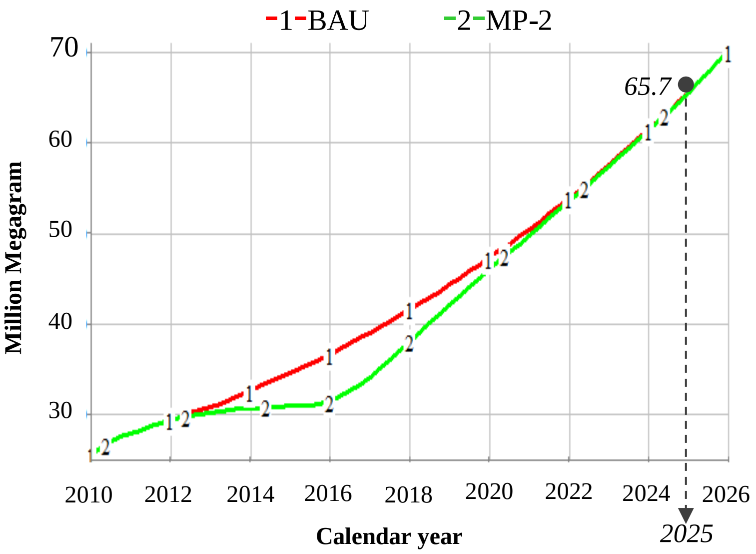
a. BAU versus MP-1 scenarios



b. BAU versus MP-2 scenarios



c. BAU versus MP-3 scenarios

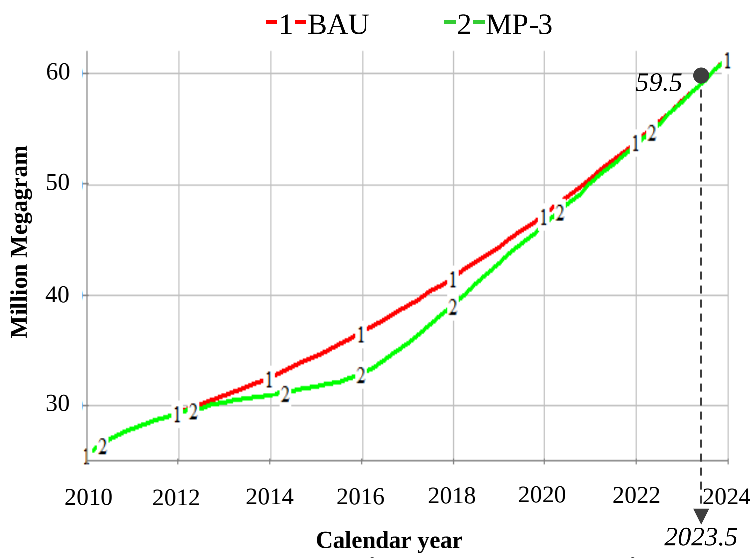


Figure 7. Breakdown in CPO production capacity as a result of the MP implementation (if the time horizon of the model is extended). Since the MP implementation (in 2011), it takes 10.5 years (in 2021.5), 14 years (in 2025), and 12,5 years (in 2023.5) for the MP-1, MP-2, and MP-3 scenarios, respectively, to increase production capacity matches the BAU level.

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does not seem to be able to pay for the breakdown in the CPO production capacity as a result of the MP implementation even by 2020. The annual average CPO yield until 2020 is projected to decline by 1.9% (around $6.7×10^5$ Mg), 6% ($2.1×10^6$ Mg), and 4.3% ($1.5×10^6$ Mg) for the MP-1, MP-2, and MP-3 scenarios, respectively. This declining yield occurs because the MP causes a temporary suspension of the palm oil plantation expansions, which automatically make the mature plantation population area grow slower than under the BAU scenario. Consequently, the production capacity of IPO industry is determined, and, thus, the MP hampers the IPO industry in meeting the market demand. The model also demonstrates that the IPO industry will experience a breakdown effect within a minimum of 10.5, 14 and 12,5 years for the MP-1, MP-2, and MP-3 scenarios, respectively (based on the simulation if the time horizon of the model is extended, see figure 7).

The declining CPO yield as a result of the MP implementation is perceived as a potential economic loss because of the failure to capture the economic opportunities (i.e., to fulfill the palm oil market demand). Thus, it is necessary to overview the potential economic loss. For the overview, we conducted a rough calculation of the cumulative value of the palm oil yield that is potentially lost during 2010 to 2020 by multiplying the declining CPO yield by the palm oil price. The total potential economic loss in the IPO industry sector during 2010–2020 is approximately 5.6, 17.1, and 12.5 billion USD for the MP-1, MP-2, and MP-3 scenarios, respectively. This value was obtained using a random simulation with various palm oil prices during July to December 2013, that is in the range of $723 to $810 USD per Mg [44]. The total potential economic loss is actually higher than that value considering the other processes/aspects related to forest conversion to plantation area, such as the forest concession fee, the timber value from forest clearing, and job creation. From this illustration (rough calculation), in terms of finances, we can say that the potential economic loss cannot be offset by a financial compensation from the bilateral agreement on REDD-plus cooperation. Moreover, the financial compensation payment depends on the achievement of Indonesia in reducing GHG emissions.

However, the MP could push the IPO industry sector to shift their method in increasing the production capacity. That is, to lead into activities that can improve the productivity of existing plantations rather than increase forest conversion. Thus, the deforestation rate and its environmental impacts can be avoided. The model experiment has demonstrated that if the IPO industry is able to improve their productivity (i.e., to gradually improve from an average of 3.1 Mg per ha in 2010 to 4 Mg per ha in 2020), required land for IPO could be reduced by approximately 41% compared with the BAU scenario. For the existing IPO plantations, we found that to increase a planting density per ha is an option for improving productivity. The IPO planting density is around 130 palm crops per ha [35], whereas in Malaysia reaches to 140-148 palm crops per ha [42, 45]. Increasing the density from 130 to 148 palm crops per ha will increase the productivity of 14% or to increase from 3.1 to 3.5 Mg of oil per ha. Another option is to use a good quality seed when replanting, it is essential not only for growing a strong and healthy crop but also for improving the yield. According to Basiron [46], by intensive breeding and research cycles that have been conducted over the last 50 years, the yields of good quality seeds can reach more than 10 Mg/ha/year. In addition, It is believed that yield improvement of 18.5 Mg of oil/ha/year can be realised in the future if the breeding research continues. However, to implement properly best practices in plantation management is also an important factor to improve productivity.

5. Conclusion

This study presents an SD application to assist with policy analysis of a trade-off between GHG emissions reduction and economic growth with regard to the implementation of the MP under REDD-plus cooperation in Indonesia. The primary goal of developing this model is to enhance the understanding of the impacts of the MP implementation associated with the supply–demand mass flows of one economic sector of Indonesia that rely on the forest. Thus, We address that the model is not meant to predict the future or to produce a quantitative projection, which may not match the actual situation in the future.

The model has demonstrated that the MP noticeably reduces GHG emissions from deforestation. However, (i) the trend of GHG reduction is only temporary; that is, using only the MP seems to halt temporary environmental degradation or to shift the environmental degradation to the next period. (ii) Indonesia may face an economic slowdown as a result of the MP implementation. Furthermore, the slowdown effect will last sufficiently long compared to the period of the MP, mainly because of the declining productivity of Indonesia economic sectors that rely on the forest conversion and use, such as mining, timber/logging, palm oil, and numerous agricultural industries.

Referring to the results, the bilateral agreement on REDD-plus cooperation seems to not be in accordance with the green economy concept of Indonesia that provides equal attention to economic growth and the environment. Because the bilateral agreement is not economically viable for Indonesia, a payment for environmental services under the bilateral agreement is un-competitive with the palm oil industry sector, which is only one of many economic sectors in Indonesia that rely on the forest. However, the MP can be an initial measure for mitigating GHG emissions from deforestation and forest degradation. Thus, whether the MP has long-term positive impacts on both economy and environment of Indonesia depends on further strategy and policy instruments, which as a continuation of the MP are absolutely necessary and should be prepared before the policy expires.

Acronyms and Abbreviations

BAU	business as usual
CO_2	carbon dioxide
CPO	crude palm oil
FFBs	fresh fruit bunches
GAPKI	Indonesia palm oil producers association
GDP	gross domestic product
GHG	greenhouse gas
GPO	global palm oil
IPOPA	Indonesia palm oil plantation area
IPO	Indonesia palm oil
LUC	land use change
MAORI	ministry of agriculture Republic Indonesia
MAPE	mean absolute percent error
MP	moratorium policy
MP-1	first phase of moratorium policy
MP-2	second phase of moratorium policy
OER	oil extraction ratio
POC	palm oil consumption
REDD	reducing emissions from deforestation and forest degradation
SD	system dynamics
USDA	united states department agriculture

Units of Measure

Mg	megagram, a measure of mass
ha	hectare, a measure of area
USD	United States Dollar

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