



Reconciling oil palm economic development and environmental conservation in Indonesia: A value chain dynamic approach

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ABSTRACT

Palm oil makes a significant contribution to the economies of Indonesia and Malaysia through private corporations, state-owned companies and smallholders, with the two countries supplying 85% of the global palm oil. Indonesia has 14 million hectares (ha) of oil palm; its palm oil exports were valued at USD 23 billion in 2017 and USD 21 billion in 2018. Both domestic and international communities, particularly the European Union (EU), have raised concerns about its sustainability and impact on forest conservation. For example, the European Parliament in 2017 issued a resolution to restrict the ability of EU countries to count palm oil-based biodiesel imports toward their renewable 2030 energy targets. This paper describes palm oil value chains in Indonesia at the national level, using value chain analysis and system dynamics modeling. The model is used to understand how the moratorium, peatland conservation, agrarian reform, and the EU biodiesel ban affect plantation expansion and production, employment, CO₂ emissions, smallholder incomes, the private sector, and government. The model provides scenarios to make Indonesian palm oil more sustainable through intensification, no-deforestation, and no-peat strategies, as well as through land swapping. There are trade-offs between economic development and environmental conservation, but win-win solutions are available. Scenarios that build synergies between Indonesian palm oil development and forest conservation can help guide the new frontiers of oil palm development in Asia, South America, and Africa.

1. Introduction

The role of palm oil in economic development and environmental degradation is a highly debated topic. Oil palm is a versatile crop, with palm oil and other derivatives used for cooking and to make margarine, detergents, and cosmetics. In the last decade, some countries have used palm oil as feedstock for biofuels as they diversify their energy supplies (Soh et al., 2003; Murphy, 2007; Ngando-Ebongue et al., 2012). The increasing global demand for food, energy, and other industrial processes correspondingly increase the demand for palm oil.

In Indonesia, palm oil significantly contributes to national development. In 2017, the export value of palm oil reached USD 23 billion (Reily and Ekarina, 2018; Tim Riset PASPI, 2018). Palm oil contributed 17% of Indonesia's agricultural gross domestic product in 2014 (MoA, 2015a,b); according to the 2013 agricultural census, about 2 million

(M) smallholders cultivate oil palm (BPS [Statistics Indonesia], 2013). The Indonesia Palm Oil Association (GAPKI) and other associated industries have employed up to 7.8 M laborers throughout the palm oil value chains (Tim Riset PASPI, 2018).

Despite economic growth, however, there are concerns that rapid development and expansion of oil palm plantations have left an undesirable ecological footprint. Oil palm expansion has been associated with the clearing of forests and peatlands (Setiawan et al., 2016; Vijay et al., 2016; Austin et al., 2017) leading to a significant amount of greenhouse gas (GHG) emissions (Miettinen et al., 2012) and loss of biodiversity (Koh and Wilcove, 2009; Lees et al., 2015; Linder and Palkovitz, 2016). Oil palm cultivation also leads to negative social impacts, such as the dispossession of land and poor working conditions on plantations (Dhialulhaq et al., 2015; Gellert, 2015). Studies in Kalimantan have studied the links between oil palm development,

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deforestation, and the involvement of private and public actors at different levels (Susanti and Maryudi, 2016; Prabowo et al., 2017). Importantly, these problems are not related to oil palm itself but to the crop's establishment and cultivation (Rival and Levang, 2014).

The Government of Indonesia (GoI) has set production and productivity targets for palm oil. In the early 2010s, the GoI set a production target of 40 M tons of crude palm oil by 2020. For the same time frame, the GoI set a productivity target known as 'Vision 35:26' with the goal of producing 35 tons per hectare (ha) of fresh fruit bunches (FFBs) with a 26% oil extraction rate (MoA [Ministry of Agriculture], 2013). To meet this target, the government introduced several incentives to support the private sector in accessing and expand plantations. It also brought smallholders to the table by formulating various partnership schemes with companies. For example, one program will allocate 12.94 M ha of convertible production forests (of a total of 68.98 M ha) for non-forestry use (MoEF [Ministry of Environment and Forestry], 2016). The GoI also plans to conduct agrarian reform on 9 M ha of land for smallholder practices, including oil palm (Setkab [Sekretariat Kabinet Republik Indonesia], 2015). The expansion of oil palm plantations aims to support Indonesia's economic growth target of over 5% for 2017–2018. Fig. 1 shows oil palm distribution in Indonesia.

At the same time, in its Nationally Determined Contribution (NDC) as an implementation framework of the Paris Agreement, Indonesia agreed to reduce its carbon emissions by 29% without foreign aid by 2030, and by 41% with foreign aid. In a business-as-usual (BAU) scenario, emissions reached 2.881 gigatons of CO₂ equivalent (CO₂e) in 2030. Indonesia's contribution to lowering emissions from land-based management could come from the following measures: sustainable agriculture and plantations, reduction of forest degradation and deforestation, land conservation, and renewable energy from degraded land. Other possible areas include energy, industrial processes and product use, and waste (GoI [Government of Indonesia], 2016).

Given that decisions over palm oil and its derivatives will have implications on economic and environmental outcomes, a model which represents the structure of palm oil value chains in Indonesia is useful. The model should be able to respond to questions around policy-relevant scenarios and should be sufficiently easy to operate.

Several models or modeling exercises on oil palm exist. Some, such as PALMSIM (Simulating growth and yield of oil palm) and APSIM (Agricultural Production Systems sIMulator), focus on the cultivation and production of palm oil (Hoffmann et al., 2014; Holzworth et al., 2014); IMPACT (International Marketing Program for Agricultural Commodities and Trade) focuses on trade (Robinson et al., 2015; De Pinto et al., 2017; Wiebe et al., 2019); GLOBIOM (Global Biosphere Management Model) combines trade with land-use models (Pirker

et al., 2016; Mosnier et al., 2017). Some exercises using econometric or computable general equilibrium models aim to analyze the impacts of trade policies (Rifin, 2011) the effect of oil palm expansion on key macroeconomic outcomes using input-output analyses (Obidzinski et al., 2014), or the impact of the oil palm moratorium on the Indonesian economy (Yusuf et al., 2018). These models, however, do not provide for value-added distribution to various actors participating in the palm oil value chains, nor do they reveal trade-offs in the current debates such as the oil palm moratorium and peatland conservation.

To this end, this study developed a model called the Indonesian Palm Oil Simulation (IPOS). This aims to understand the value chain of the palm oil industry. It provides options for policymakers and decision-makers about possible futures for the Indonesian palm oil industry at the national level. This model can also support communications among different stakeholders to determine a road map of palm oil development in Indonesia. The model represents the actual value of palm oil at the national level, as suggested by Dudley et al. (2008).

This paper discusses three aspects of the model: (1) the structure of the palm oil industry; (2) the palm oil value chain at the national level; and (3) scenarios related to national-level policies, such as: (a) the moratorium on oil palm expansion as stated in Presidential Instruction No. 8 of 2018; (b) peat protection as stated in Government Regulation No. 57 of 2016; (c) agrarian reform; and (d) land and forest fires. This paper aims to contribute to the debate around national oil palm and palm oil policies and their implications for smallholder incomes and carbon emissions.

2. Methods

This study applied the value chain analysis (VCA) approach using system dynamics modeling. The system dynamics model used here is a state-change model observing feedback (Forrester, 1961, 1999). System dynamics modeling was implemented through steps comprising the development of a conceptual model, specification, model verification, and scenario building (Grant et al., 1997; Jakeman et al., 2006). The VCA consists of several steps: (1) map the start of the value-added chain; (2) conduct a field survey; and (3) evaluate findings and develop intervention scenarios (Kaplinsky and Morris, 2001; Herr et al., 2006; Purnomo et al., 2014).

2.1. IPOS model conceptualization and specification

The architecture of the IPOS model follows the VCA (Fig. 2). It has three main components: (1) the palm oil value chain; (2) the policy development scenarios; and (3) the output indicators to evaluate the results of each scenario. The policy scenarios feed into the existing palm

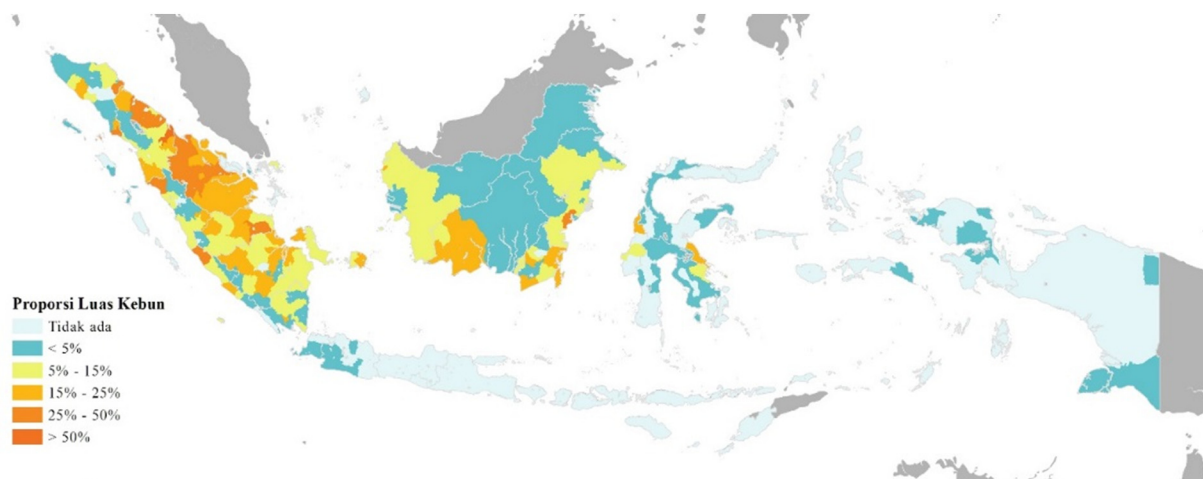


Fig. 1. Distribution of palm oil plantations in Indonesia 2014 (DGP [Directorate General of Plantation], 2016).

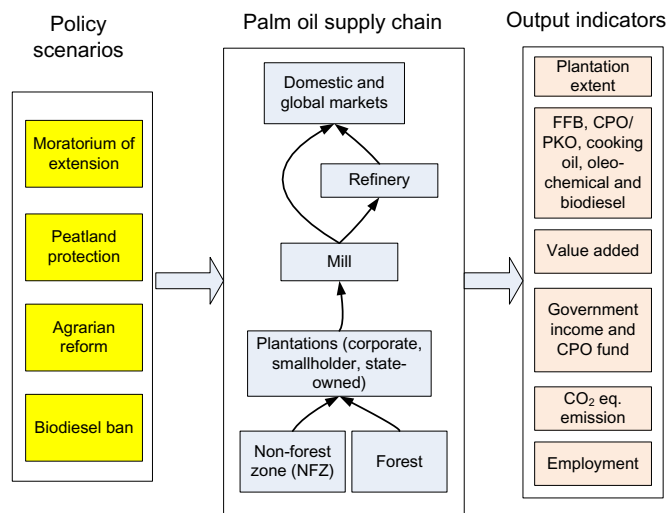


Fig. 2. Architecture of the Indonesian Palm Oil Simulation (IPOS) model.

oil system, then produce output indicators. The palm oil value chain consists of plantations, palm oil mills, refineries, and markets. Growers produce fresh fruit bunches (FFB) which are processed by mills into crude palm oil (CPO) and palm kernel oil (PKO). These are transformed by refineries into cooking oil, oleo-chemicals, and biodiesel. These products enter domestic and global markets to generate revenue which flows back to the refineries, mills, producers, and the government.

The IPOS model produces several outputs, such as the area of oil palm plantations (ha), the production quantity of primary products such as FFB and CPO/PKO, and derivatives such as cooking oil; these are value-added for each actor, carbon emissions, and labor in palm oil industries. The BAU scenario generates output indicators in the current context, if they continue. Four policy scenarios were reviewed: (1) the moratorium on plantation expansion; (2) peat protection; (3) agrarian reform; and (4) the biodiesel ban.

Data in this model are from survey results, official sources (such as central government ministries and agencies, local governments and their staff), research institutions, and scientific publications. Table 1 shows the categories of data and sources used in the model. The model approaches real-world scenarios and was developed using the Stella 9.0 system dynamics software, in combination with Microsoft Excel to improve the output quality of Stella.

The model has exogenous and endogenous variables. Exogenous variables are independent and affect the model without being affected by the model, while endogenous variables are dependent and are generated by the model. The exogenous variables of the model include land uses, plantation area, policies, and palm oil price. The endogenous variables include palm oil supply and value chains, employment, and CO₂ emissions. The price of palm oil is determined by the supply of palm oil and other vegetable oils from producers such as Malaysia and Brazil, as well as on consumer demand. This study did not simulate consumer behavior or other palm oil producers, both of which affect the price system. Law enforcement, corruption, and other institutional

elements are complex and exogenous to the model, but they do affect the expansion of oil palm plantations; this study also did not simulate these. Instead, time-series regression was used to formulate oil palm expansion.

The IPOS model shows the production flow from growers to end-users. The palm oil supply chain covers oil palm plantations, palm oil mills, refineries, and markets. The most extensive use of CPO in Indonesia is in the cooking oil industry, followed by the margarine and shortening industries, the oleo-chemical industry, the bath soap industry, and the laundry soap industry.

Fig. 3 presents a causal loop diagram of IPOS and illustrates material flows: (a) new plantation, FFBs and CPO/PKO and its derivatives; (b) money from the market to the refinery and mills, and mills to the grower; and (c) carbon flux for each activity. Human activities affect the whole value chain. For example, fires and peatland protection will reduce the supply of FFB to mills, while agrarian reform will lead to more land available for oil palm plantations.

We provide the details of the IPOS model specification in Supplement 1. The specification offers parameters for each component of the model.

2.2. The IPOS model architecture

The model consists of three components: estates or plantations, mills and refineries, and markets. The observed indicators are (1) FFB, CPO/PKO and oil derivatives; (2) value-added (money); (3) carbon emissions; and (4) labor. The execution of the model depends on the stock data, rate of change, and the following BAU assumptions:

- The initial stock and rate of change of estate, mill, and refinery draws on linear regressions of annual data over 20 years.
- The price of palm oil draws on the estimates of secondary data.
- Price feedback covers only the rate of change in plantation areas.

Fig. 4 shows the interface of IPOS. Supplement 2 provides the details of each sector of the model.

Section 3 presents each component of the model and its execution. The model begins with the market and is followed by the oil palm plantations, the mill, and the refinery.

The main parameters in the dynamics of oil palm and FFB production are presented in Table 2. Each oil palm plantation undergoes four processes: planting, maturing, producing FFB, and plant death. These processes represent a conveyor with different transit times. Oil palm starts maturing at four years, reaches maturity at 5–19 years, declines in productivity by age 20–25, and dies after 25 years.

There are two components in the palm oil production sub-model: mills and refineries. The conversion parameters of FFB, CPO, and PKO are presented in Table 3. CPO and PKO are processed into cooking oil (81%), oleo-chemical (10%), and biodiesel (9%).

2.3. Scenario development

This model aims to examine the impacts of key policies related to oil palm that are currently under discussion, and to develop future policy options. These policies are: (1) a moratorium on oil palm development

Table 1
Category of data and their sources used in the model.

No	Classification of data type	Data sources
1	Structure of palm oil value chains	Scientific publications
2	Oil palm land uses, mill, refinery	Central government or ministries
3	National development plans, agrarian reform	Government agencies
4	Benchmarking of palm oil projections	Private business associations, such as Indonesian Palm Oil Association (GAPKI)
5	World palm oil price, supply and demand	International organizations, such as the World Bank
6	Biomass utilisation	Think tank organizations, such as Economic Research Institute for ASEAN and East Asia (ERIA)

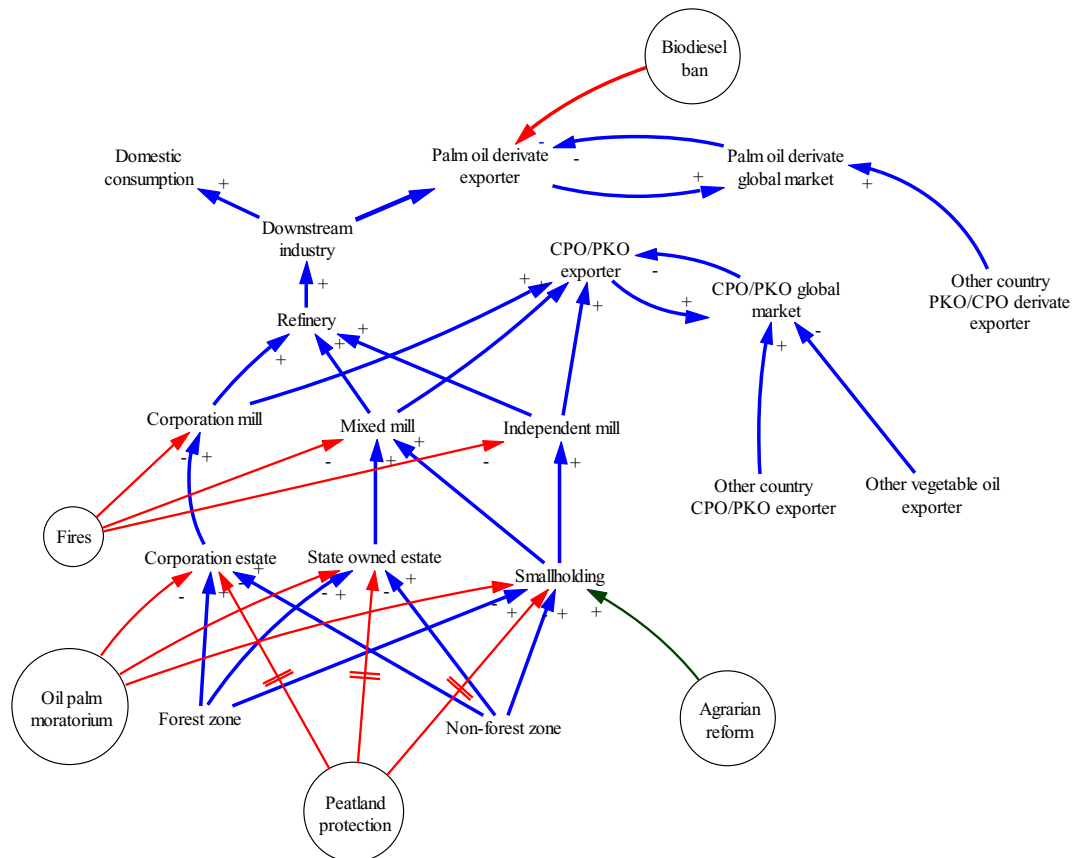


Fig. 3. Causal loop diagram of the Indonesian Palm Oil Simulation (IPOS) model.

as stated in Presidential Instruction No. 8 of 2018; (2) peat protection as stated in Government Regulation No. 57 of 2016; (3) agrarian reform; (4) prevention of and countermeasures against land and forest fires. For each policy, a scenario is proposed which can compensate for the policy's impact on producers and help them shift toward more sustainable palm oil production.

3. Results

3.1. Model results under BAU

3.1.1. Dynamics of the palm oil market

The execution of the market sub-model is shown in Fig. 5. The

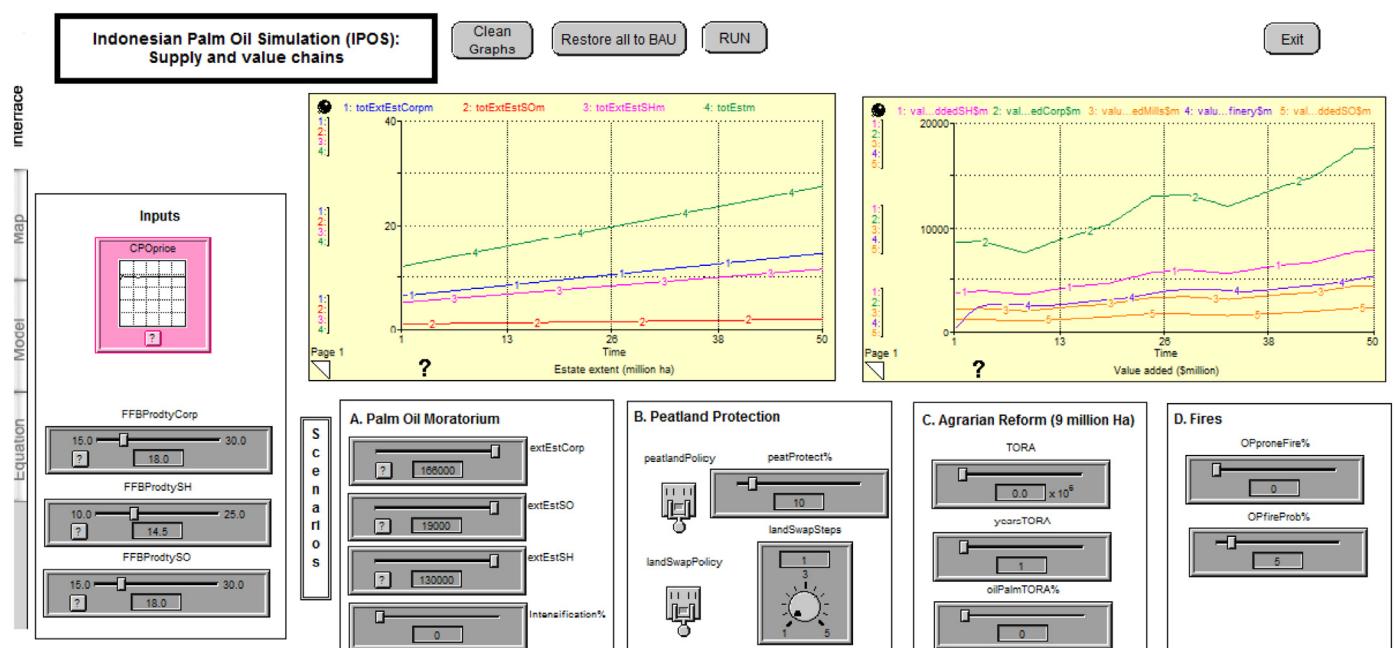


Fig. 4. Indonesian Palm Oil Simulation (IPOS) model interface.

Table 2
Parameters of oil palm plantation dynamics at the beginning of the simulation, year 2015 (t_0).

Stock	Initial area (ha)	Death and replanting (ha/year)	Expansion (ha/year)	Planting rate (ha/year)	Harvest area (ha)	Productivity (tons FFB/ha)
Private estates	5,964,974	13,252	164,751	178,751	4,574,581	18.03
Smallholder estates	4,763,797	28,853	141,423	170,276	3,451,265	14.52
Government-owned estates	755,787	6138	20,004	26,241	593,108	17.98
Total	11,484,558	48,243	326,178	375,268	8,618,954	Average: 16.84

Table 3
Factor conversion of palm oil processing.

	CPO	PKO	Cooking oil	Oleo-chemical	Biodiesel
Conversion					
FFB	21,7%	4,3%	–	–	–
CPO	–	–	81%	10%	9%
PKO	–	–	81%	10%	9%
Distribution					
Domestic	74%	90%	30%	17%	33%
Export	26%	10%	70%	83%	67%

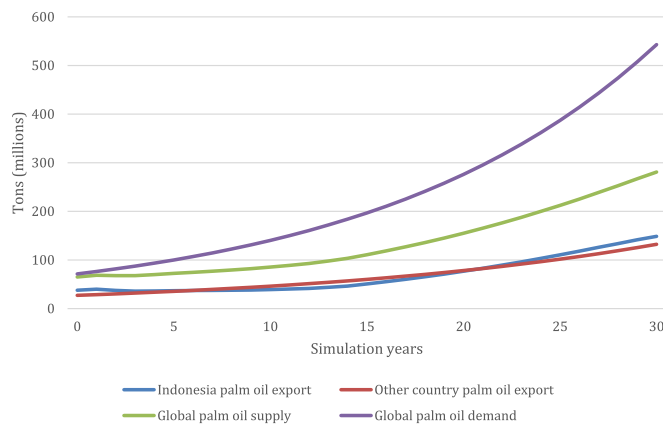


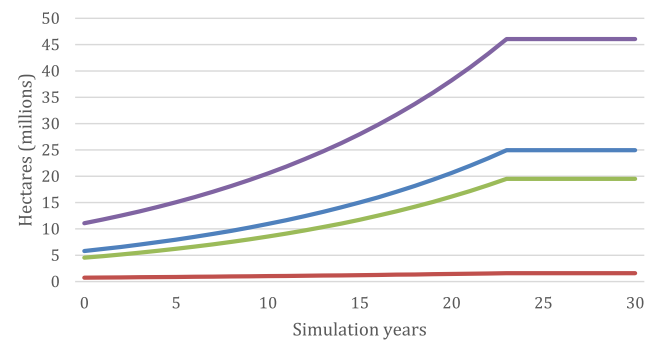
Fig. 5. Simulation of palm oil market dynamics using the IPOS model.

global demand for palm oil grows at 7% per year, while demand for other vegetable oils grows at 4% per year. The palm oil exports of other countries grow at 5.4% per year (Bruno, 2017). Palm oil supply cannot meet demands, resulting in global shortages. The Indonesian domestic market also experiences palm oil demands that exceed the supply, with the gap between supply and demand continuing to grow.

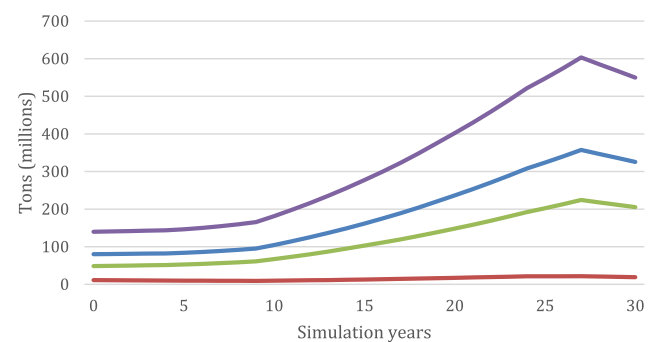
3.1.2. The dynamics of oil palm plantations, production of FFB and deforestation

The area covered by oil palm plantations will continue to grow in proportional percentages until that area reaches the maximum amount of land suitable for oil palm. Mulyani et al. (2003) and Mulyani and Las (2008) placed this area at 44.7 M ha. Once that area has been reached, it will remain constant (Fig. 6a). The production of FFB is projected to increase from 142 M tons to 603 M tons after 27 years (year 2042; year 2015 was used for the baseline of simulation year) as shown in Fig. 6b. After that, the FFB production will be oscillated around that amount because of aging and replanting palms with the same extent.

Oil palm development to achieve its goals, suitable land will need to be repurposed from other uses (Table S1.4). Deforestation and conversion of shrubland, including peat forest and peat shrub, should occur to make room for new plantations. Approximately 33.5% of oil palm expansion comes from disturbed and undisturbed forests, and 26.3% from shrubland and grassland. At the current rate of plantation development, 12 M ha will be deforested and 9 M ha of shrubland converted after 23 years (year 2038). Assuming that half of the shrubland is either degraded or composed of secondary forests, 16.5 M ha will be



(a)



(b)

Fig. 6. Simulation of projected oil palm development (a) and FFB production by private companies, state-owned enterprises, smallholders, and all actors (M tons of FFB) (b).

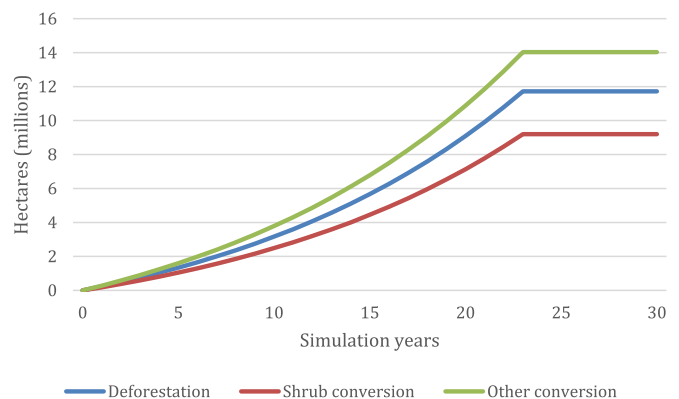


Fig. 7. Simulation of cumulative deforestation, shrubland, and other land conversion (million ha).

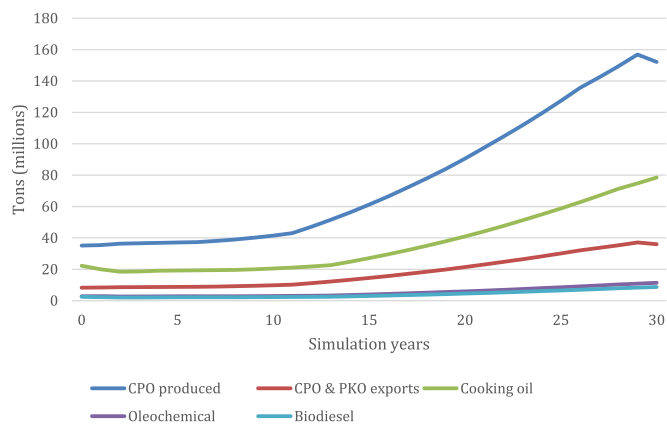


Fig. 8. Production of palm oil derivatives and CPO/PKO exports (million tons).

deforested after 23 years (Fig. 7). Since most lands were once primary forests, it can be assumed that some of them degraded into secondary forests and then further into shrublands. International definitions specify shrubs as woody perennial plants, often without a definite crown and generally with heights between 0.5 m and 5.0 m (Gschwanter et al., 2009).

3.1.3. Dynamics of palm oil mills, refineries, and palm oil production

Results from the 30-year simulation are shown in Fig. 8. The amount of raw materials producing CPO and PKO increased from 35 M tons to 157 M tons. The export quantity increased from 8 M tons to 35 M tons, while 122 M tons were processed into derivative products at domestic refineries. The production of cooking oil increased from 20 M tons to 82 M tons, oleo-chemical production increased from 3 M to 12 M tons, and biodiesel production increased from 2 M tons to 9 M tons.

3.1.4. Value of exports, government income, and CPO Fund

The value of exports consists of CPO/PKO and their derivatives (Fig. 9). Palm oil exports grew from USD 21 billion to a maximum of USD 89 billion after 32 years, and then oscillated. The export composition consists of one-third CPO and PKO and two-thirds palm oil derivatives. Following the increase in exports, government income from palm oil increased from USD 2 billion to USD 9 billion. Likewise, the CPO Fund increased from USD 1 billion to USD 4 billion.

3.1.5. GHG emission dynamics of the palm oil industry

The carbon sub-model shows emissions from the plantation and palm oil processing sectors of 160 M tons of CO₂e at the initial period. The emission represents about 15% of total emissions reported by the GoI in the First Biennial Update Report under the UN Framework Convention on Climate Change (UNFCCC) in 2012. The most significant

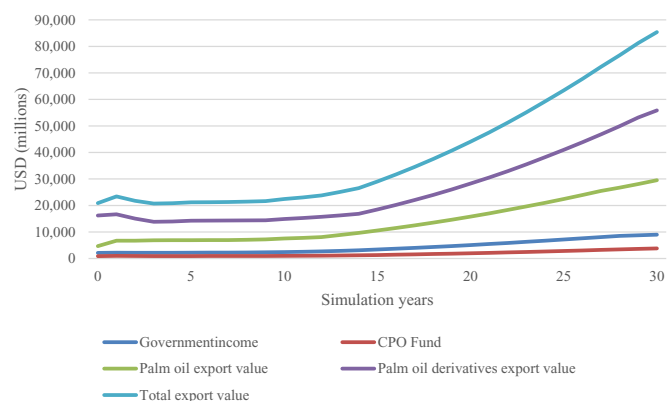


Fig. 9. Export, government income and CPO Fund (million USD).

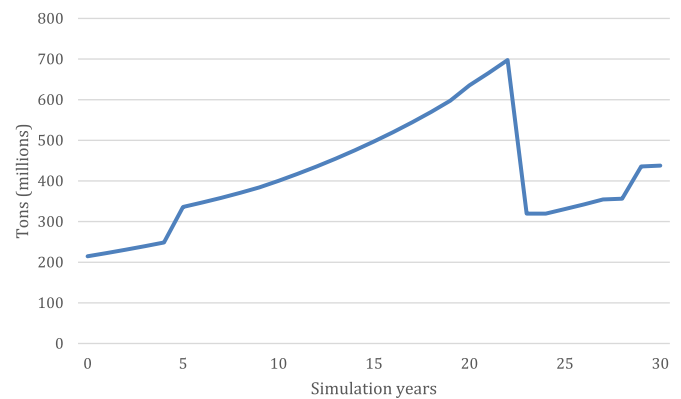


Fig. 10. Annual CO₂ emissions from Indonesian palm oil (million tons CO₂e).

GHG emissions from the plantation and palm oil processing sectors come from peat oxidation from existing estates, land-clearing activities, and palm oil mill effluents. Peatland oxidation is the largest single source of carbon emissions. Approximately 2.3 M ha of oil palm plantations on peatlands emit more than 100 M tons of CO₂e per year. Peat oxidation occurs due to decreasing groundwater levels, resulting in decomposition of soil organic matter. Current sustainability measures can reduce, but not halt, carbon emissions from peat. Land clearing activities and peatland fires combined account for about another 38% of carbon emissions; palm oil mill effluent (POME) also causes considerable emissions. Simulation of palm emissions reached 716 M tons CO₂e after 22 years (Fig. 10), based on the assumption that 21% of oil palm plantation is prone to fire and 5% of it was burned.

3.1.6. Employment

The Indonesian palm oil industry directly employs more than 6 M people (Fig. 11). The workforce has increased due to the expansion of oil palm plantations and mills. Over the next 22 years, under BAU condition, the industry could employ 23 M people.

3.2. Comparing model results with other projections

We verified the IPOS model by matching simulation results on BAU conditions with data and estimates. IPOS structures are logical and commonly used in supply chain studies and value chains of agricultural and forest commodities. The structure of the supply chain consists of farmers, plantations, and forests, followed by primary and secondary processing industries. The sale of primary and secondary products occurs in domestic and international markets.

BAU simulation results from the IPOS follow a logical pattern, with quantities that are traceable to their origins. Table 4 shows the difference between simulation outputs and realities. The main reason for

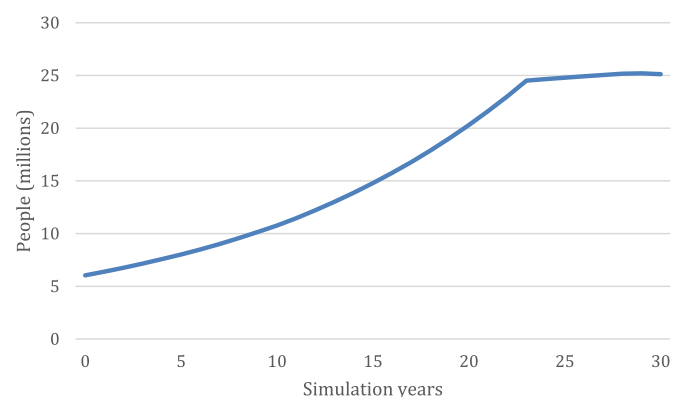


Fig. 11. Oil palm employment in Indonesia.

Table 4
Simulation outputs and benchmarks.

No	Indicator	Simulation result	Benchmark	Difference	Benchmark source
1	Palm oil production in 2019 (M tons)	37.08	36.42 41.32 40.2	1.81% – 10.26% – 7.76%	MoA ^a MoA ^b GAPKI
2	Cooking oil domestic consumption in 2020 (M tons)	5.77	3.16 6.89	82.37% – 16.19%	MoA ^b GAPKI ^c
3	Estate extent in 2020 (M ha)				
	Total	12.64	13.68	– 7.60%	GAPKI ^c
	Smallholder	5.17	6.93	– 25.35%	GAPKI ^c
	Corporation	6.63	6.04	9.83%	GAPKI ^c
	State-owned	0.84	0.72	16.36%	GAPKI ^c
4	Extent of yielding plantation 2019 (M ha)	8.66	8.12	6.70%	MoA ^a
5	Export palm oil (CPO/PKO) in 2020 (M tons)	8.71	7.10	22.61%	GAPKI ^c
6	Biodiesel in 2020 (M tons)				
	Domestic	0.71	10.19	– 93.03%	GAPKI ^c
	Export	1.42	1.50	– 5.17%	GAPKI ^c
7	Cooking oil in 2020 (M tons)				
	Domestic	5.77	6.89	– 16.19%	GAPKI ^c
	Export	13.38	14.57	– 8.19%	GAPKI ^c
8	Oleochemical in 2020 (M tons)				
	Domestic	0.47	0.74	– 35.78%	GAPKI ^c
	Export	2.30	1.30	77.73%	GAPKI ^c
9	Direct employment in 2030 (M people)				
	On-farm worker	4.75	6.30	– 24.60%	Infosawit ^d
	Mill worker	0.29	0.17	71.40%	Infosawit ^d
Difference					
	Maximum			– 93.03%	
	Minimum			1.81%	
	Average			2.57%	

^a MoA, 2015b

^b MoA, 2016

^c GAPKI [Indonesian Palm Oil Association], 2017

^d InfoSAWIT, 2015.

these differences is that the simulation uses data from official sources. The mills also obtain FFB from unofficial or unrecorded sources.

Table 4 shows a comparison between the simulation results and benchmarks from various sources. The simulation results comprise palm oil production, domestic consumption, the extent of oil palm plantations, palm oil exports, domestic trade, and direct employment. While modeling is based on data from 2015 and before, the verification year varies from 2019 to 2020 to 2030, depending on the availability of benchmark data. The most substantial difference is for the domestic biodiesel trade, with - 93.03% between the simulation and the benchmark. This indicates that the simulation result is much lower than GAPKI's reference. Meanwhile, the smallest difference is 1.81% from the palm oil production as stated by the Ministry of Agriculture. The average difference is 2.57%, which is relatively low.

3.3. Policy scenarios

3.3.1. Effect of the moratorium vs. intensification on deforestation and FFB production

The GoI issued a regulation that placed a moratorium on new permits for oil palm plantation for corporations, but not for smallholders. The extent of moratorium's benefit will depend on the length of time that it remains in place. The moratorium can also reduce the increase in FFB production compared to BAU since smallholders produce lower amounts of oil palm. Fig. 12.a shows slowing deforestation due to a 10-year moratorium on oil palm expansion by corporations. Fig. 12.b demonstrates how the area covered by oil palm plantations will also be affected by the same 10-year moratorium.

Under BAU conditions, FFB production would reach more than 600 M tons. The moratorium will reduce FFB production (Fig. 12.c), but it is possible to compensate for this decline through intensification, which would increase productivity by 20% and would bring FFB production to around BAU levels. This scenario shows that increasing the

productivity of existing plantations can compensate for the effect of a moratorium.

This scenario is plausible due to the low productivity of Indonesian oil palm, particularly for smallholders. The current average productivity is 16.84 tons FFB/ha, with smallholders producing 14.52 tons FFB/ha and private companies producing 18.03 tons FFB/ha. Increasing productivity by 20% translates to an average productivity level of 17.42 tons FFB/ha. This level, however, is still lower than the current productivity of several large oil palm plantations in Indonesia (20.21 tons FFB/ha) and in Malaysia (22.45 tons FFB/ha) (Byerlee et al., 2017).

In the model used in this study, the moratorium is implemented for 10 years instead of the 3 years currently stated in the Presidential Regulation No 8 of 2018. This was done to amplify the moratorium's effect. A shorter moratorium term would result in a smaller effect.

3.3.2. Effect of peatland protection and fire prevention on income and carbon emissions reduction

This scenario of 'No peatland and no fire,' may decrease FFB and CPO production, as well as business revenues. The study estimates that 2.4 M ha (21%) of existing oil palm plantations are on peatlands. Protecting and restoring peatlands will therefore reduce the oil palm plantation areas. To compensate for area lost to protected and restored peatlands, a land swap was introduced into the model to provide new land for oil palm plantations. This land swap reduces emissions from peat oxidation and land-clearing activities in peat soil, and also reduces the risk of fire in drained peatlands.

Fig. 13.a shows that CO_{2e} emissions under peatland protection and fire prevention are lower compared to BAU. However, as shown in Fig. 13.b, FFB production is also lower, as is income from palm oil (Fig. 13.c). The land swap is introduced at the end of the rotation period, when replanting is done on mineral land rather than on peatlands. Land swapping results in increases in both FFB production levels

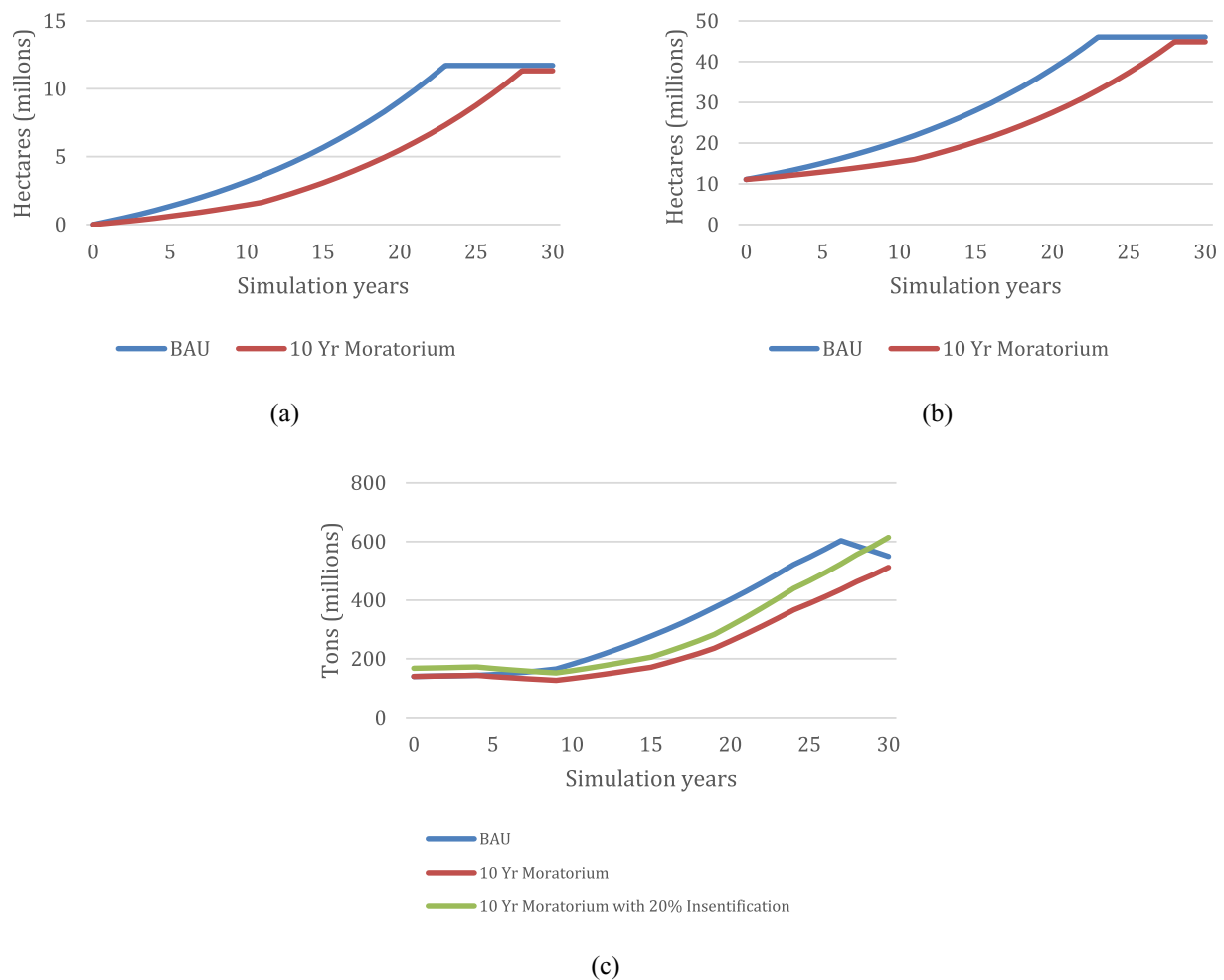


Fig. 12. Effect of a 10-year oil palm moratorium on deforestation (a); plantation area (b), and FFB production (c).

and income (Fig. 13.c). Therefore, swapping oil palm from peatlands to mineral soil could reduce emissions from the BAU scenario without affecting overall FFB production.

3.3.3. Effect of agrarian reform on smallholder incomes

In this scenario, 9 M ha of land are allocated to farmers for various uses. An additional 1.8 M ha of smallholder land cultivated with oil palm, or about 20% of the total area earmarked under the agrarian reform program was added to the simulation. This area would increase the proportion of smallholder land under oil palm and surpass areas owned by corporations within five years of implementation. In addition, overall FFB and CPO production would increase under agrarian reform (Fig. 14).

3.3.4. Effect of a biodiesel export ban by the EU on revenue

On 4 April 2017, the European Parliament issued a resolution on palm oil and deforestation of rainforests (EU [European Union], 2017). The resolution embraces the problem of oil palm development and associated deforestation, environmental degradation, human rights violations, and CO₂ emissions. This resolution was accepted by the European Parliament and is subject to further discussion with the EU Council. If adopted, a ban on palm oil-based biodiesel exports will take effect in 2030.

A different percentage of each Indonesia palm oil product is exported. The export amounts are: CPO (26.3%), PKO (10.25%), cooking oil (70%), oleo-chemical (83%), and biodiesel (67%). Of the 67% of biodiesel exported, 20% is exported to EU countries. The ban would, therefore, reduce the export percentage of biodiesel from 67% to 54%.

Fig. 15 shows that the EU ban is insignificant in reducing the total export value, which is projected at USD 44,064 M without the EU ban and at USD 43,597 M with the EU ban in 2035. A decrease of USD 467 M or 1% would therefore be incurred due to the EU ban (Fig. 15).

4. Discussion

4.1. Discussion of results

In this modeling exercise, “sustainability” was not comprehensively defined due to the data limitations for the observed indicators. Sustainability in this context means that the palm oil industry meets several indicators, including forest conservation and CO₂ emissions reduction. Economic sustainability indicators are the maintenance of or increase in palm oil production as well as the total income from palm oil. The equity indicator is the maintenance or improvement of smallholders' share of income from palm oil compared to total income.

Actions to improve the palm oil economy involve expansion and intensification. However, expansion can reduce the extent of forest. Gunarso et al. (2013) revealed that 33.5% of oil palm plantations were on forestlands (including peat forest), 26.3% on shrublands (including peat shrublands), 34.1% on agroforests, and 6% on other lands (see Table S1.4 of Supplement 1). Shrublands originally began as secondary forests that experienced logging or fires. In total, 59.8% of oil palm plantations exist on forest or shrubland areas that have displaced primary forests or areas which were previously primary forests. The high proportion of forests and shrublands converted to oil palm is the impetus behind the moratorium on oil palm expansion for corporations.

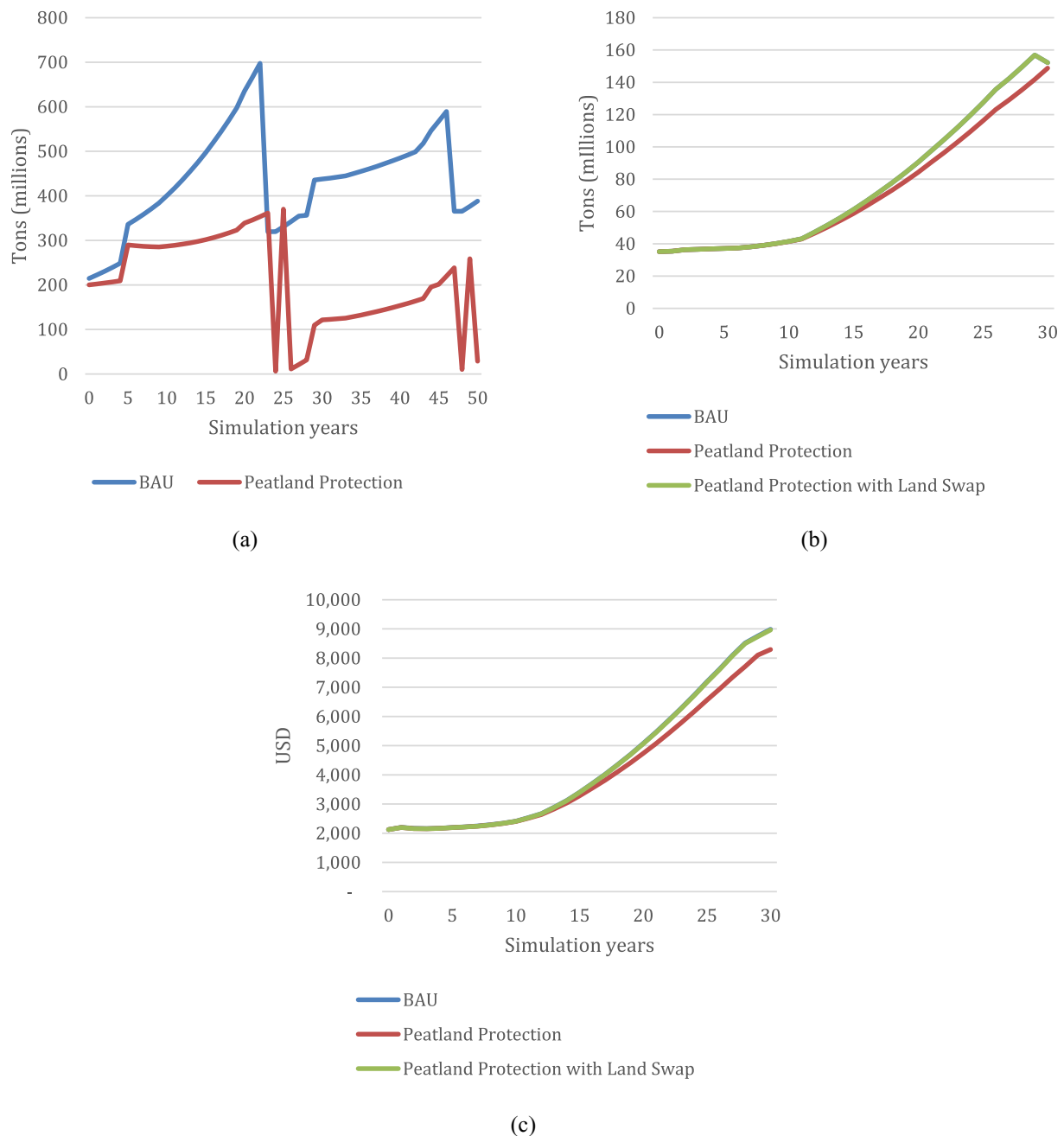


Fig. 13. Effect of the 'Peatland Protection and Fire Prevention' scenario on total emissions (a); CPO production (b); and incomes with land swap (c).

The moratorium would also reduce the excess supply of CPO. However, it does not include smallholder oil palm. Under the moratorium, Indonesian oil palm plantations would grow by only 1.08% annually; without it, they would grow 4.66%.

This model shows that the moratorium has the potential to reduce forest conversion. It also shows that the moratorium should be implemented in combination with increased productivity. The commitment of private sector actors to achieve zero deforestation is critical (Austin et al., 2017; Pacheco and Komarudin, 2017). Through intensification, there is an expectation that smallholders will reduce the need to expand their estates into the forests (Nurfatriani et al., 2018). Smallholder productivity is approximately half that of corporations. Increasing the productivity of palm oil from the 2017 level of 2.64 tons CPO/ha to 2.83 tons of CPO/ha (a 7.1% increase) can compensate for a yearly loss of about 1.3 M tons of CPO. One major challenge will be to encourage smallholders to improve their cultivation. The CPO Fund

could play a key role in supporting this aim by mobilizing the fund allocated for oil palm replanting. There is also a need for more co-ordinated public policies and a strong public-private partnership (Pacheco et al., 2017).

Massive migration due to oil palm development should also be considered (Sandker et al., 2007). Migration is related to another critical challenge called the "Jevons paradox," which states that increasing productivity or intensification will actually increase expansion instead of reducing it. It is based on the logic that increasing productivity will provide more benefits to existing plantation holders but will also attract new actors. Increasing productivity must go hand-in-hand with law enforcement to limit or prohibit further expansion.

Approximately 20.8% of oil palm plantations grow on peatlands (Table S1.4 of Supplement 1). Allowing peatlands to regenerate as forests or shrublands will reduce CO₂ emissions. However, implementing peatland restoration without a land swap will reduce

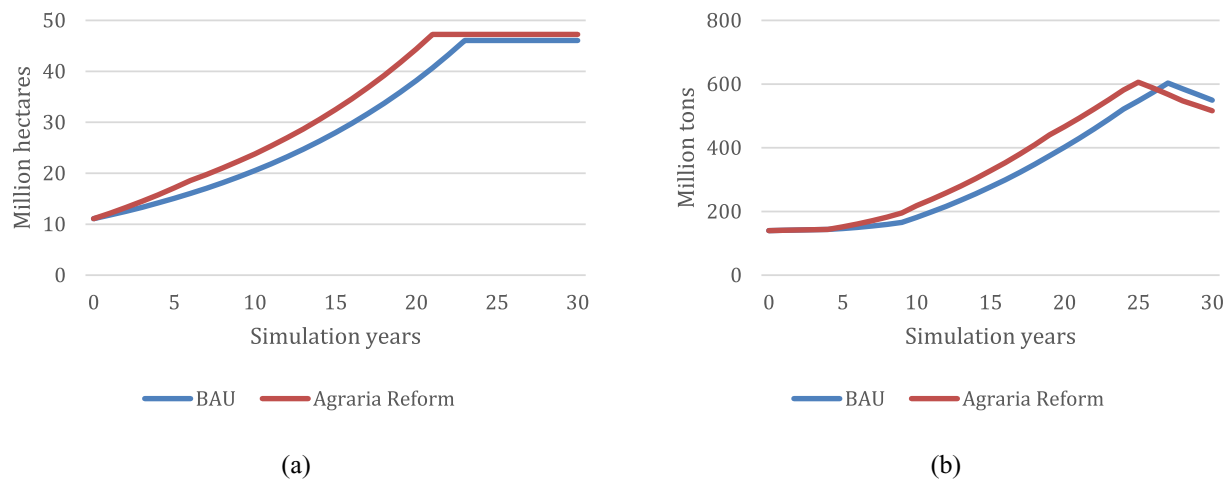


Fig. 14. Effect of agrarian reform scenario for 5 years and 20% share of *Tanah Objek Reforma Agraria (TORA)* on oil palm area (a) and FFB production (b).

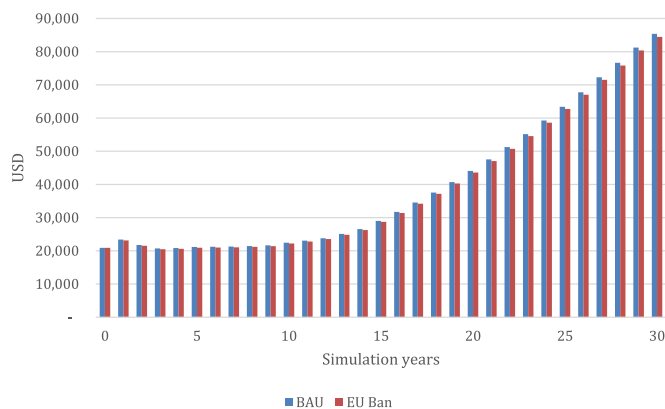


Fig. 15. Effect of EU ban on palm oil-based biodiesel export to total export value.

income from palm oil; therefore, a land swap is necessary to maintain income. Implementing land swaps would require about 2.9 M ha of mineral land.

The government, through the Ministry of Environment and Forestry (MoEF), Ministry of Agriculture (MoA), and National Land Office (Badan Pertanahan Nasional Republik Indonesia, or BPN), must work together to find suitable land for the land swap. Given that the MoEF has delineated 12 M ha of forest zone for conversion to agricultural land, that area can potentially become a source for land swapping. Existing carbon stocks, infrastructure, mills, refineries and oil palm holders' interests must be taken into consideration when making a determination. Corporations could view the land swap through the logic of economics. As long as new land parcels are sufficiently large, have no overlapping rights, and are profitable, corporations would not object to the land swap. Meanwhile, land swaps for smallholders will require facilitation, especially if the smallholders are poor.

Oil palm plantation development should not involve fire. Purnomo et al. (2018) explain how good governance of palm oil value chains, engaging producer organizations, moving to a higher value chain or reducing intermediaries for mills, and certification incentives can potentially work well. Good governance involves integrating enforcement from district government and economic incentives from CPO mills. Incentives from certification and moving to a higher value chain can compensate for the illegal benefits of using fire.

Providing 9 M ha of land to poor farmers through agrarian reform would extend the area where oil palm is currently cultivated. If 20% of that land was used for oil palm plantations, the 11.4 M ha of plantations

(2015) would increase by 1.8 M ha. Land for agrarian reform (*Tanah Objek Reforma Agraria, TORA*) can be sourced from forest or non-forest zones. Areas earmarked for TORA must have low carbon stocks; otherwise, agrarian reform will result in higher CO₂ emissions and loss of ecosystem services such as biodiversity and water regulation. Another challenge is to ensure that those who receive land are indigenous people and poor farmers. Participatory mapping at the village level is necessary to identify the recipients.

The potential impact of the EU biodiesel ban also needs serious consideration. Although the direct financial loss of export would be only 1%, the EU ban can trigger similar actions from other potential export destinations such as Norway, the United States, China and India. Also, the scope of the ban could extend beyond biodiesel to cooking oil and oleo-chemical products. Therefore, Indonesia needs to transform its oil palm industry to become more sustainable, with clear environmental and social indicators. Sustainable uses of peatland and fire prevention are essential (Purnomo et al., 2017).

There are clear ways to transform Indonesia's palm oil industry without losing income. Indonesian palm oil can contribute to environmental conservation through the plantation moratorium, peatland conservation, and fire prevention. The sustainable palm oil industry can contribute to the income of smallholders, corporations, and government, and create and sustain employment for millions of people.

4.2. Discussion of methods

Policymakers need to understand the synergies and trade-offs among economic, social, and environmental factors in their policy-making exercises to improve their accountability. This is not trivial: failing to understand synergies and trade-offs will limit policymakers' ability to learn and use the model and scenarios (Morecroft and Sterman, 2000; Purnomo et al., 2011).

The value chains and system dynamics models can integrate variables related to the economy, equity, and environmental conservation. This interdisciplinarity helps clarify the complexity of the palm oil industry in Indonesia. System dynamics is a 'white box' modeling process, which enables users to follow and understand the process by which the inputs and scenarios produce outputs. They are also able to recognize possible intervention points and who will be affected. Influencing actors participating in palm oil value chains is key to reducing deforestation and forest degradation (Purnomo et al., 2014).

Challenges came up during the value chain analysis and modeling process. The first relates to the level of complexity. It was necessary to be selective when choosing the relevant variables in the model; otherwise, qualifying and quantifying the connections among each variable would not be possible. Many relationships are not yet known. The

second concern is relevant to the model users, such as policymakers, business associations, and conservationists. If all desired variables had been used, the model would be too complex and challenging to follow. Policymakers will not be convinced that the model is useful if they cannot fully understand how inputs and scenarios result in specific outputs. Likewise, if the model is too simple, it will not reflect the system's reality. It is therefore necessary to have the right balance between complexity and simplicity. The IPOS model aims to strike such a balance for the Indonesian palm oil industry, so that it becomes a useful tool for policymakers. Further, the non-linearity performance of natural resources, social and economic systems will add to the complexity of any future scenarios (Campbell et al., 2001).

5. Conclusions

There are currently conflicts between proponents of the lucrative palm oil industry and those promoting environmental conservation; there is also international criticism due to deforestation and carbon emissions. However, plausible policy scenarios to reconcile oil palm development and forest conservation do exist. This paper explores policy scenarios involving a moratorium, productivity, peatlands, land swapping, and agrarian reform. Improving productivity by 20% can compensate for the moratorium on plantation expansion. Removing an estimated 2.4 M ha of existing oil palm plantations on peatlands and swapping them with mineral soil lands would reduce CO₂ emissions without affecting overall FFB production. The land swap would also reduce the fire risk in drained peatlands. Agrarian reform would increase the area of oil palm under smallholders by 2.4 M ha, and in five years they would become the main actors of FFB production, surpassing large enterprises. The direct economic loss of not exporting biodiesel to the EU after 2030 amounts to USD 467 M, or only 1% of total exports. However, the ban could trigger other potential export destinations such as Norway, the United States, China, and India to act similarly. Likewise, the scope of the ban could extend from biodiesel to cooking oil and oleo-chemical products. Sustainability poses a possible advantage for Indonesia's palm oil industry under the expansion moratorium, through intensifying productivity, swapping peatlands for mineral lands, and agrarian reform. These options provide lessons for other palm oil countries, as well as for other commodities when economic and environmental considerations are in conflict.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.forpol.2020.102089>.

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