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Projection of Biodiesel Production in Indonesia to Achieve National Mandatory Blending in 2025 using System Dynamics Modeling

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ABSTRACT

Biodiesel has been produced since 2006 in Indonesia and regulation of biodiesel blending has been set, but the actual blending rate was never reached the target. The research aims to increase biodiesel production to achieve mandatory target and reduce diesel oil import. It will project biodiesel production achieving demand in Indonesia until 2025 and proposes some strategies to increase blended biodiesel production by constructing system dynamics modeling. The research shows, there are 3 scenarios to increase biodiesel production; palm oil cultivation land, palm oil productivity and refined CPO shared. To meet blended biodiesel demand, cultivation land should be increased to 3.2-6.5% per year, productivity should be fixed to 12.54 ton/ha and refined CPO shared should be adjusted to 56.9-65.4%. This scenario also will reduce diesel oil import to 7.16-9.82 million kL per year. Refined CPO shared is the most influenced variable; therefore the government should consider to make refined CPO export limitation policy.

Keywords: Blended Biodiesel Production, System Dynamics Modeling, Refined CPO Export
JEL Classification: Z

1. INTRODUCTION

Increasing of energy needs, limitation of fossil-fuel-based energy resources, fluctuation of fossil fuel global price and environmental issue of greenhouse gases (GHG) emission have led management energy crises in Indonesia and forced the Government of Indonesia (GOI) to increase fossil fuel import and price. Biodiesel is one of the alternative solutions in order to depress fossil fuel import and GHG emission, due to its similarity characteristics with diesel oil, sustainability proven and environmentally friendly (Musango et al., 2012). GOI has been producing biodiesel from Crude Palm Oil (CPO) since 2006 and became the highest blending rate of biodiesel producer in the world (de Vries et al., 2010). GOI also has set mandatory target of biodiesel-blending-diesel oil since 2009 until 2025, but the blending rate implementation has never reached the target. Many problems occurred regarding biodiesel utilization, such as feedstock limitation, CPO is also used as food and most of CPO production is being exported, biodiesel price is higher than diesel oil price and biodiesel distribution and mandatory has not equally spread in Indonesia's regions and sectors.

Many researchers have been observed how to increase biodiesel production through several methods, such as: Anderson et al. (2013) and Musango et al. (2012) were comparing and choosing the most efficient feedstock, Lin et al. (2013) was analyzing the most suitable blending rate for biodiesel and diesel oil, Aransiola et al. (2014) was using the most updated technology of biodiesel processing by comparing various technologies, Imtiaz et al. (2015) was choosing the proper properties of biodiesel reactor in order to attain optimum result and Enciso et al. (2016) was planning the right policies to support the development of biodiesel utilization, Lensink and Londo (2010) were using Monte-Carlo Simulation, while Schade and Wiesenthal (2011) were using BioTrans Model.

The research aims to simulate some scenarios in order to achieve national mandatory blending rate of biodiesel and diesel oil using system dynamics modeling. System dynamics has ability to understand the resulted behavior and to predict the interpretation of the time-based policy modification of the system. System dynamics has been widely used in many scopes of fields and several purposes, such as: presenting and predicting electricity demand in Indonesia (Sulistio et al. 2017), assessing the technology sustainability through policy interference in South Africa (Musango et al., 2012), analyzing biofuel production and determining feasibility production (Escalera et al., 2008), and developing a comprehensive sustainability model of biodiesel industry in Indonesia (Hidayatno et al., 2011).

2. LITERATURE REVIEW

2.1. Current Status of Palm Oil Plantation in Indonesia

The utilization of palm oil as biodiesel feedstock is currently being developed in West Africa and South East Asia for the last decade (Nongbe, 2017). Indonesia, as tropical country, has the biggest potential of palm oil production, it was reported in 2015, Indonesia and Malaysia contributed 83% of global production, of which Indonesia shared 51% and Malaysia shared 34% (Mielke and Mielke, 2018).

Palm oil is characterized by its high amount of medium-chain saturated and monounsaturated fatty acid (Rutz and Janssen, 2007) and perennial crop, which means its oil production will be continues and uninterrupted, compared to soybean and rapeseed (Lam et al., 2009). It also has higher productivity, needs less fertilizer, water and pesticide (Mekhilef et al., 2011), average world palm oil's yield is 3.68 ton/ha/year, whereas soybean has 0.36 ton/ha/year and rapeseed has 0.42 ton/ha/year (Basiron, 2007).

The derived products of palm oil refinery processing are 21.5% for Crude Palm Oil (CPO), 5% for both Palm Kernel Oil (PKO) and Palm Kernel Cake (PKE), and the remaining is palm oil mill's waste such as fiber, empty fruit bunch and POME (Palm Oil Mill Effluent) (Wicke, et al., 2008). CPO is the most used palm oil's product as biodiesel feedstock, thus it will be referred as CPO. In tropical region, the maximum palm oil's yield reaches 4.27-4.63 ton/ha/year (de Vries et al., 2010). Oil palm

Figure 1: Shared percentage of: (a) palm oil plantation; (b) CPO production in Indonesia based on the region

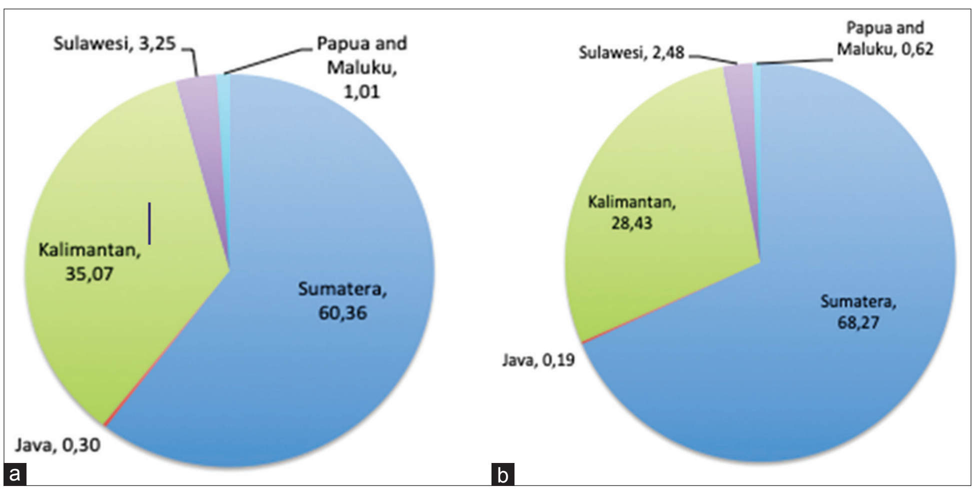
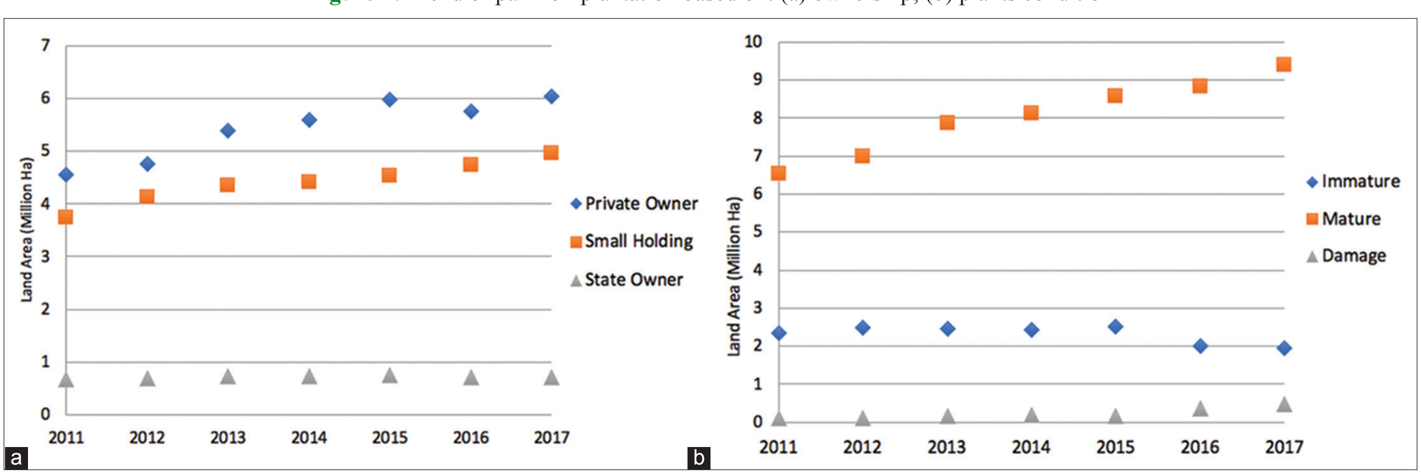


Figure 2: Trend of palm oil plantation based on: (a) ownership; (b) plants condition



plantations in Indonesia have expanded rapidly in Sumatera and Kalimantan, due to its vast forests and climate conditions (Rai, 2010). According to Directorate General of Estate Crops Indonesia, shared percentages of production and plantation area are given on Figure 1.

Based on the ownership, palm oil plantation in Indonesia can be classified into 3 categories: State-owner plantation; Private-owner plantation; and Small-holding plantation area. Whereas based on the plant's condition, the plantation area is devided into 3 categories; immature plants; mature plants; and damage plants. Immature plant is palm oil with age of 0-4 years starting from initial plantation, while mature plant is palm oil plant that has started to produce fresh fruit bunch at 5-25 years of plantation and damage plant is above 25 years plantation and the plant stops producing the oil.

Figure 3 2017, total plantation area in Indonesia reached 11.26 million Ha and CPO production was 31.07 million ton, with average productivity 3.625 Ton/Ha (Aransiola et al., 2014).

According to Indonesia Oil Palm Statistics, the CPO Production would tend to increase during 2011-2015, with growth rate 5.38%-8.42% per year and it reached 33.2 million ton of CPO production in 2016 (Indonesia Statistics Bureau, 2016).

Most of CPO production in Indonesia is exported in form of raw and refined CPO, around 70.18% of total production in 2016, but refined CPO is dominated the export, the remaining is consumed by domestics, such as food, oleochemical and biodiesel. The average usage of domestic consumption is 22.5%. Indonesia shared 57% of global CPO export in 2016 and India became the biggest importer with 55.81% of total CPO export from Indonesia (Korindo, 2018). Figure 3 gives the illustration of CPO utilization in Indonesia from 2011-2016.

2.2. Palm Oil-Based Biodiesel Statistics in Indonesia

In general, there are 3 methods to produce biodiesel from vegetable oil or animal fat: oil based-catalyzed transesterification; oil direct acid catalyzed transesterification; and oil conversion through fatty acid. Oil based-catalyzed transesterification is mostly used in biodiesel conversion process, due to its high conversion ratio, up to 98%. It also has minimum side effects and reaction time (Singh and Singh, 2010).

FAME is the type of biodiesel that commonly produced in Indonesia with conversion ratio 0.826 kg-biodiesel/kg-CPO. The glycerin is produced as co-product with ratio corresponding to 0.167 kg-glycerol/kg-biodiesel (Kamahara et al., 2010).

In 2017, there are 32 biodiesel refinery plants in Indonesia, with installed capacity 11.547 million kL and 25.11 % used capacity. During 2011-2017, used capacity had been under 50% because the increasing installed capacity was higher than demand (Dharmawan et al., 2018).

Table 1 gives data statistics of biodiesel supply and demand in Indonesia and it shows that biodiesel production was significantly rose in the last 2 years.

Figure 3: CPO utilization in Indonesia

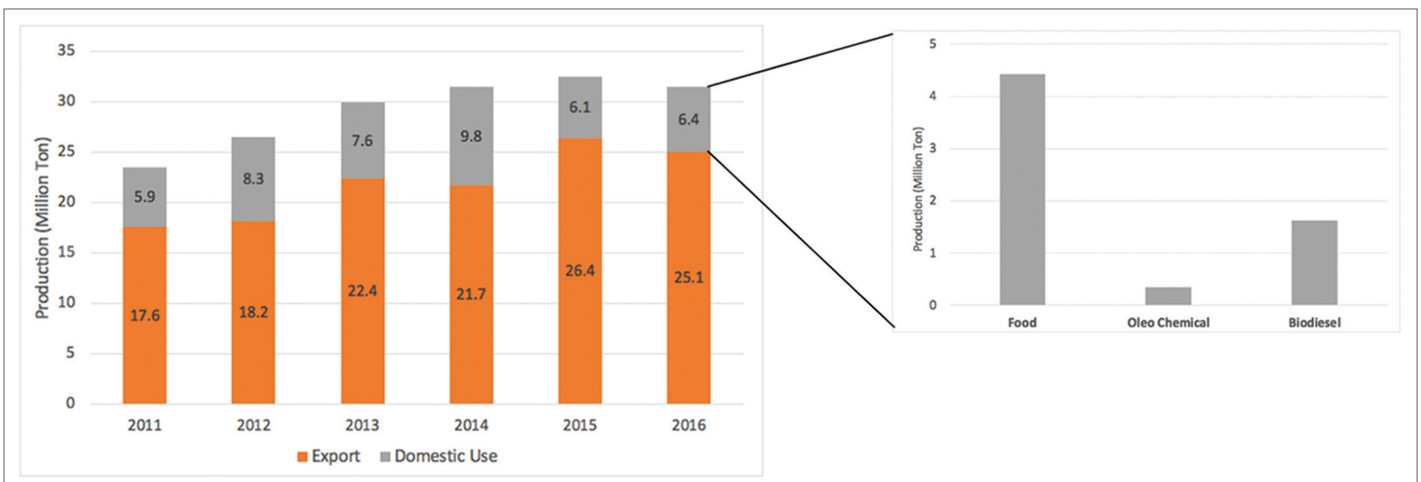


Table 1: Biodiesel supply and demand in indonesia during 2011-2017 (USDA, 2018)

Years	Capacity		Biodiesel (Million kL)			
	Installed (Million kL)	Used (%)	Production	Import	Export	Domestic Consumption
2011	3.921	45.91	1.800	0	1.440	0.358
2012	4.881	45.07	2.200	0	1.515	0.670
2013	5.670	49.38	2.800	0	1.800	1.048
2014	5.670	52.91	3.000	0	1.350	1.600
2015	6.887	17.13	1.180	0	0.343	0.860
2016	10.898	33.55	3.656	0	0.478	3.008
2017	11.547	25.11	2.900	0	0.200	2.800

2.3. Biodiesel Policies in Indonesia

Indonesia has been developing renewable energy in the past decade. It can be seen from the presidential regulation No. 79/2014 about national energy policy that set 23% renewable energy shared in 2025 and 31% in 2050 of total energy mix. Then the general plan of national energy was regulated in presidential regulation No. 22/2017, declared that biofuel usage in 2025 is 4.9% of total renewable energy and 7.1% in 2050. It is implied that GOI is targeting biofuel production in the amount of 15.6 million kL in 2025 and 54.2 million kL in 2050 (Dharmawan et al., 2018).

Some strategies used by the GOI to develop the utilization of biofuel are: converting fossil fuel to biofuel in transportation, industry and electrical generation sectors; increasing production and utilization of biofuel; and providing energy-dedicated land.

Table 2: Actual biodiesel blending rate in Indonesia for PSO transportation sector

Years	Mandatory blending rate (%)	Actual blending rate (%)
2009	1	0.4
2010	2.5	0.7
2011	2.5	1.1
2012	2.5	1.8
2013	10	2.9
2014	10	5.4
2015	15	2.6
2016	20	10.8
2017	20	8.9

The latest regulation of biofuel utilization is regulation of the ministry of energy and mineral resources (MEMR) No. 12/2015 about acceleration of biofuel mandatory in Indonesia, has set the biodiesel blending rate, in transportation sector, 30% in 2020 to 2025. It is also called B30 mandate.

On July 2015, GOI has founded Oil Palm Plantation Fund Management Agency (BPDPKS) as part of financial support mechanism to support domestic biodiesel consumption by collecting the palm oil export levy to offset the price gap between biodiesel and diesel oil. The fund collected USD 2.3 billon in period 2015-April 2018 and has dispensed USD 1.7 billion for biodiesel incentives (USDA, 2018).

GOI through MEMR has issued a regulation No. 41/2018 about expanding the use of biodiesel to the non-Public Sector Obligation (non-PSO) for transportation use. GOI was also issued Presidential Decree No. 66/2018 about biodiesel incentives from BPDPKS for non-PSO sector [USDA, 2018]. The regulations are pushed to issue due to the actual blending rate cannot meet the target (B20). B20 should be applied on January 2016, but in 2016 and 2017, the actual blending rates are 8.9% and 13.7% respectively (USDA, 2018).

Figure 4: Conceptual diagram of biodiesel production system

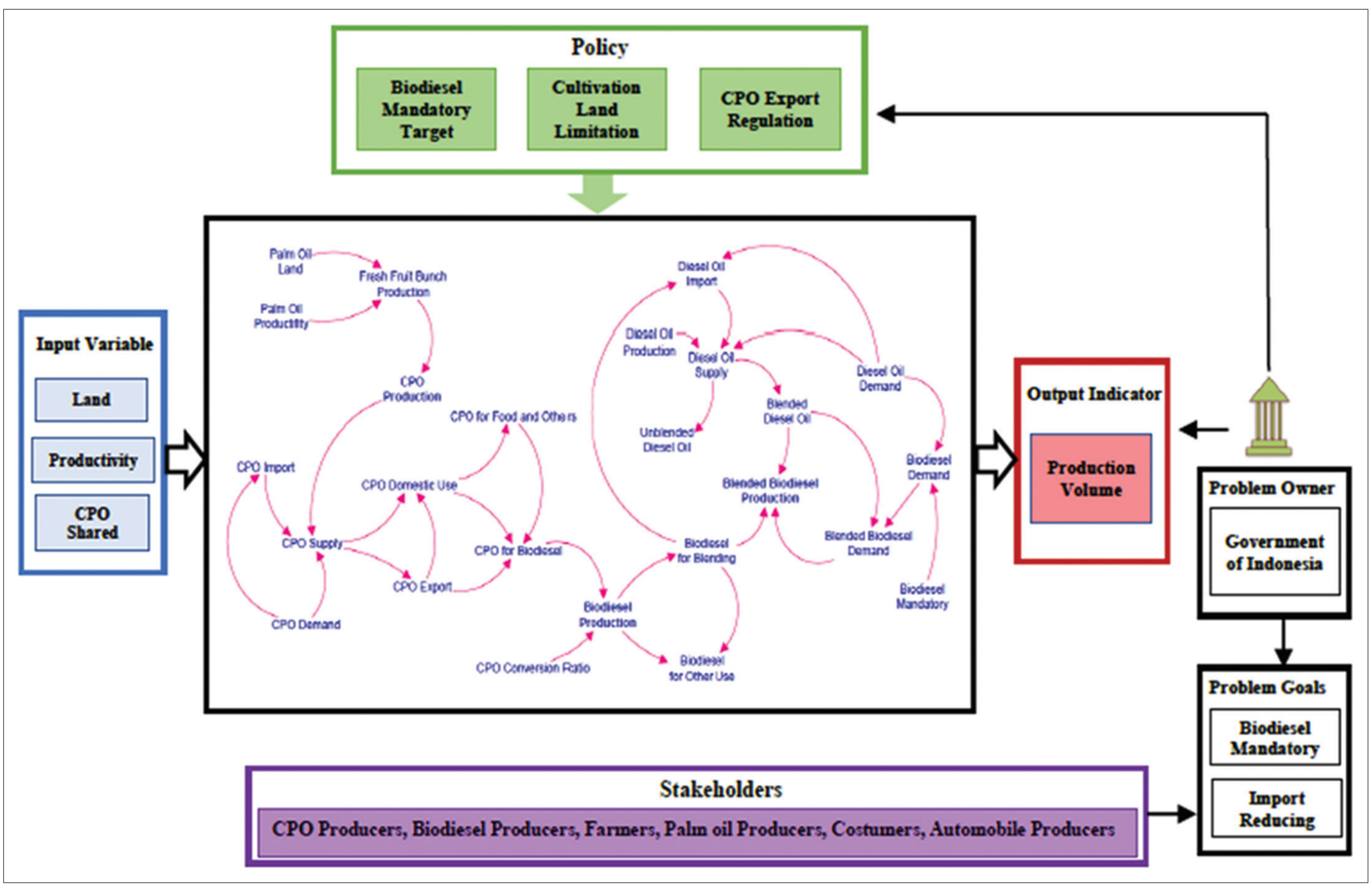


Figure 5: Stock flow diagram of palm oil plantation model in Indonesia

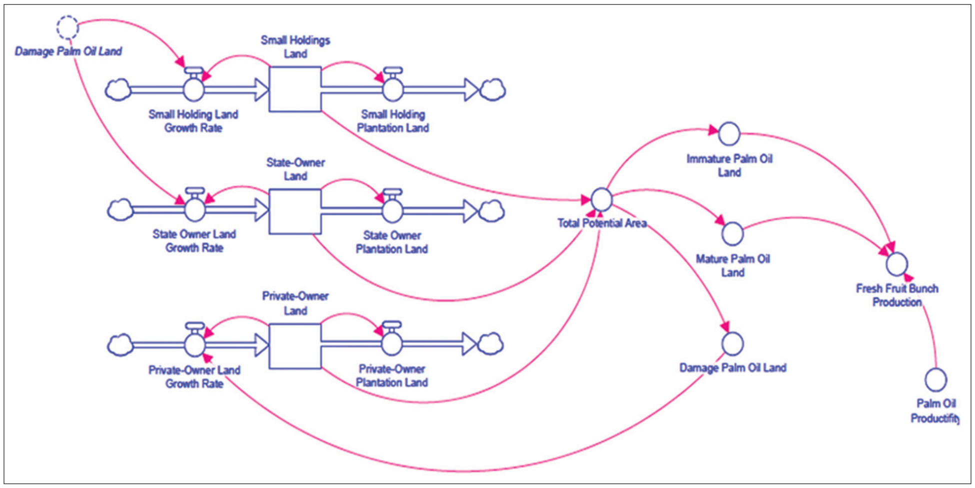
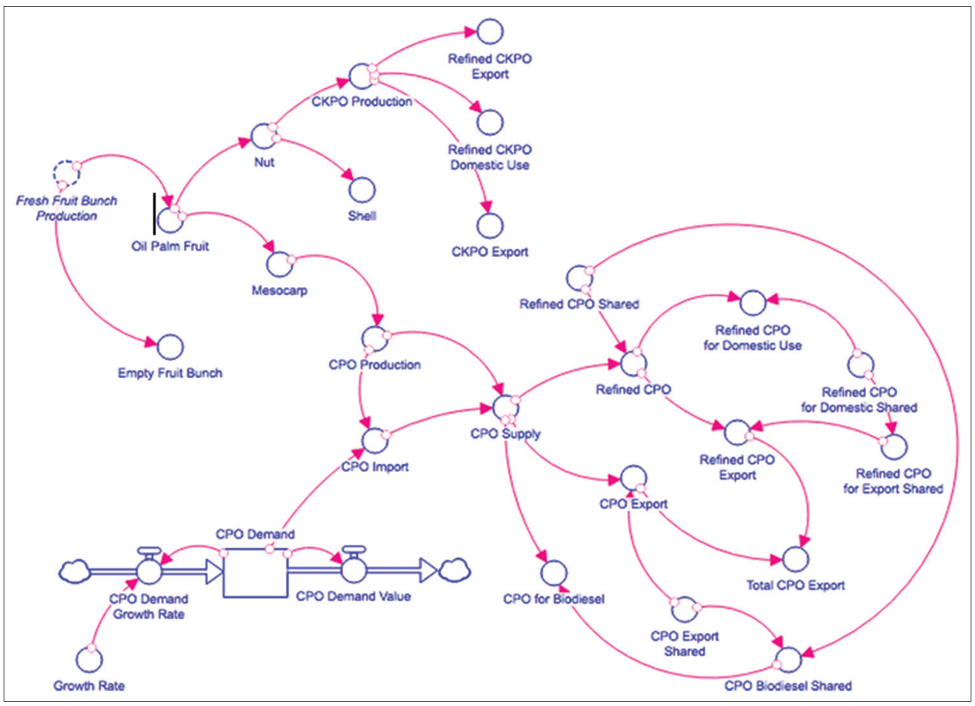


Figure 6: Stock flow diagram of CPO refinery model



The biodiesel use in non-PSO sector needs additional CPO consumption up to 0.865 million ton in 2018 and 2.5 million ton in 2019. Table 2 shows the comparation between mandatory and actual blending rate in Indonesia during 2009-2017

3. METHODOLOGY

3.1. Model Conceptualization

The research is started by assigning conceptualization model for the system. This stage will set model purpose, the constraints, input variable, output indicator, dynamics hypothesis and causal loop diagram. The next step is model development by data collection and analysis with stock flow diagrams, then continues to model validation/verification and the last step is scenario simulations.

Figure 4 shows the conceptualization diagram of whole systems. The main input parameters, which influence biodiesel production are palm oil land, palm oil productivity and CPO shared, while the output indicator is biodiesel production volume. The causal loop is also given on Figure 4. It consists of 3 main modules, palm oil plantation module, CPO refinery module and biodiesel refinery module.

3.2. Model Development

Model development stage is conducted by constructing modules, related variables and its interactions. The research has 3 main modules, starting from palm oil plantation, CPO refinery and biodiesel refinery module.

3.2.1. Palm oil plantation model

Figure 5 indicates the palm oil plantation system in Indonesia. The aggregate of land cultivation area is total land based on the

Figure 7: Stock flow diagram of biodiesel production model

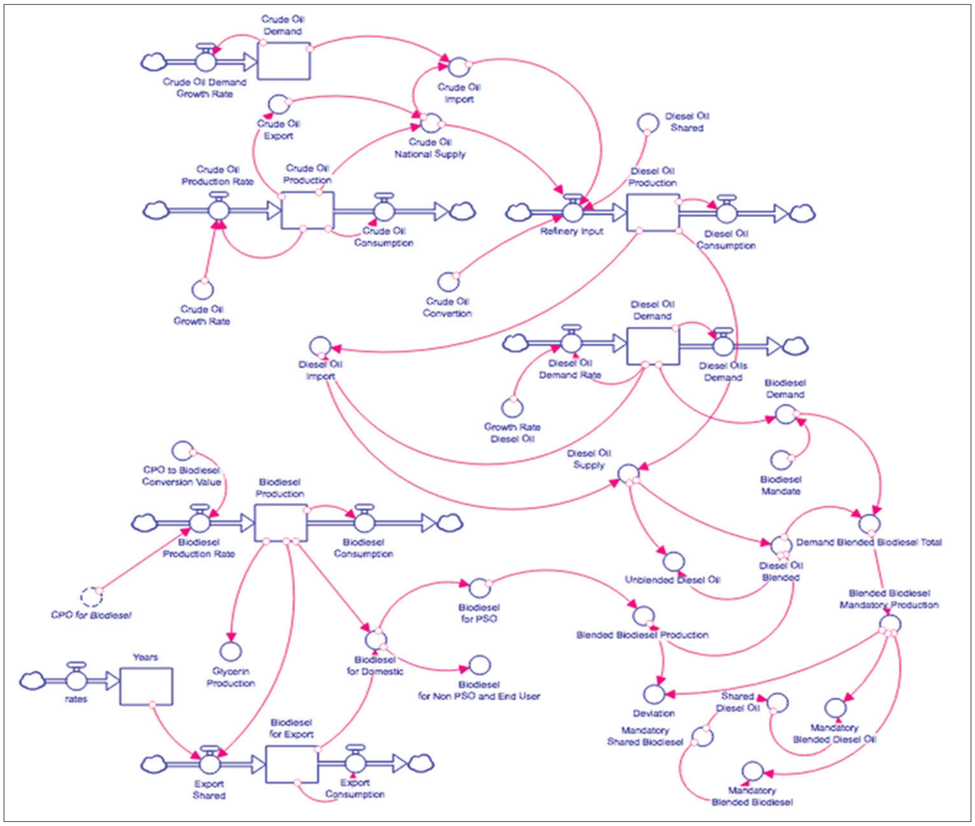
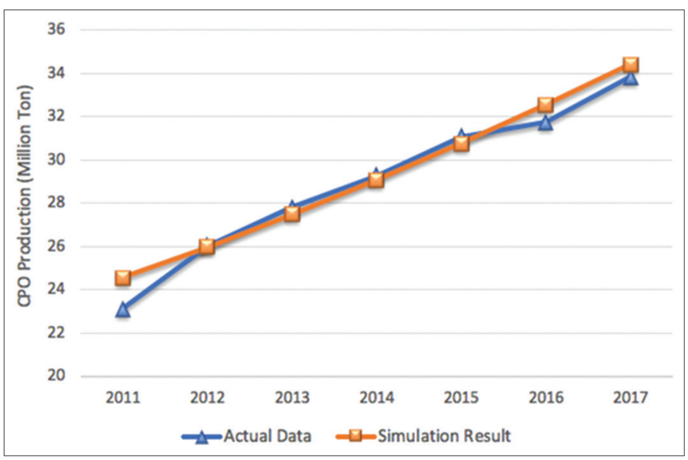


Figure 8: Comparison of CPO production between the data and model



ownership, while Fresh Fruit Bunch (FFB) production is the output parameter of the system. It can be driven either by the palm oil land or palm oil productivity.

Figure 6 illustrates the CPO refinery system in Indonesia. FFB production from plantation module will be the input of this system. FFB will produce CPO with ratio 1: 0.2249 ton. It also shows the CPO supply demand balanced and output indicator of the module is CPO for biodiesel which can be adjusted from the CPO shared for export and domestic use.

3.2.2. Biodiesel production model

Figure 7 shows the stock flow diagram of biodiesel production system. Biodiesel production is driven by CPO shared for biodiesel and CPO-to-biodiesel conversion value. At a conventional biodiesel plant, 1 L biodiesel is produced from 1.19 kg CPO, 0.14 kg methanol, 0.02 kg catalyst, 0.092 kg diesel oil and 0.039 heavy kg fuel oil (Harahap, et al., 2019).

3.3 Model Validation

Model validation is a stage to assess the reliability of constructed model. Using statistical test of Root Mean Square Error (RMSE), the model is validated. Eq. (1) gives RMSE formulation. It measures the error between two data sets, actual data (Ai) and simulation results of the model (Si).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left| S_i - A_i \right|^2}{n}} \quad (1)$$

The acceptable RMSE value is 0.6-1, the validation test shows RMSE value of the model for CPO Refinery variable is 0.78 and biodiesel production variable is 0.796. The value is in the acceptable range, therefore the model is verified and validated.

Figure 8 shows the comparation graph between actual data and simulation result for CPO production in CPO refinery module.

4. RESULTS AND ANALYSIS

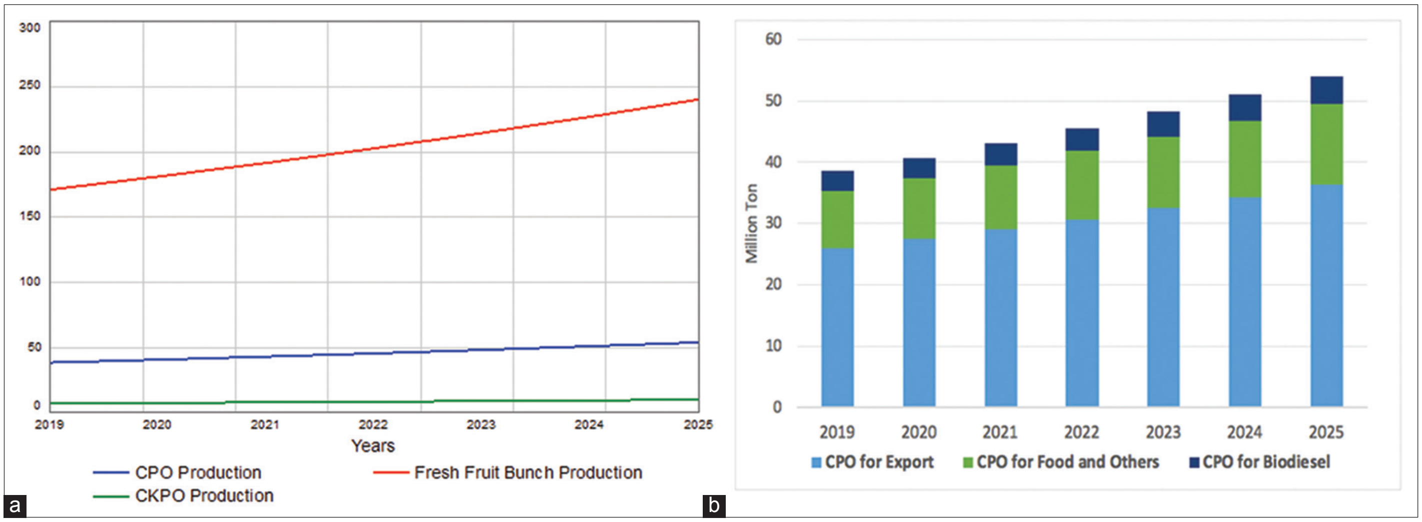
4.1. Projection of CPO Supply and Demand in Indonesia

CPO Production and its related variables are a function of FFB production. While 1 kg of FFB produces 0.2276 kg CPO and

Table 3: Projection of blended biodiesel production in Indonesia

Years	Blended biodiesel production (Million kL)	Diesel oil for blending (Million kL)	Diesel oil shared (%)	Biodiesel for blending (Million kL)	Biodiesel shared (%)
2019	31.794	28.965	91.10	2.829	8.90
2020	33.782	30.790	91.14	2.992	8.86
2021	35.895	32.730	91.18	3.165	8.82
2022	38.139	34.791	91.22	3.348	8.78
2023	40.524	36.983	91.26	3.541	8.74
2024	43.058	39.313	91.30	3.745	8.70
2025	45.751	41.790	91.34	3.961	8.66

Figure 9: Projection of: (a) FFB, CPO and CKPO production in Indonesia; (b) shared CPO consumption



0.042 kg CKPO. The projection model of CPO plantation and refinery is shown on Figure 9(a). The figure compares FFB production, CPO and CKPO production in Indonesia during 2018-2025.

During the projection period, there is no unusual activity, therefore the trends grow as the land cultivation growth. Figure 9(b) shows statistical result of CPO consumption projection in Indonesia during 2018-2025. It can be seen, that CPO export will dominate CPO demand, the trend continues and so does the growth trend. Food and other usage take the second place of CPO consumption and CPO for biodiesel also shows the similar trend.

4.2. Projection of Biodiesel Production in Indonesia

CPO supply for biodiesel will be an input for biodiesel production system. Besides producing biodiesel, it also produces glycerin with amount of 0.167 kg glycerin for 1 L of biodiesel produced (Harahap et al., 2019). Biodiesel will supply domestic and export market. Domestic market of biodiesel is mostly for transportation sector and categorizes to PSO (Public Sector Obligation) and non PSO. PSO refers to obligation carried out by state-owned companies to serve public needs, which non-commercial and non-profit oriented and 90% of biodiesel supply is consumed by PSO transportation (USDA, 2018). Electrical utility run by the state (PLN) has already implemented the blending mandatory of B30, but the effective blended rate is 8-12% (USDA, 2018). Meanwhile in industrial sector, GOI has planning to implement B15 for mining and B5 for train transportation in 2018.

Figure 10: Projection of biodiesel production in Indonesia

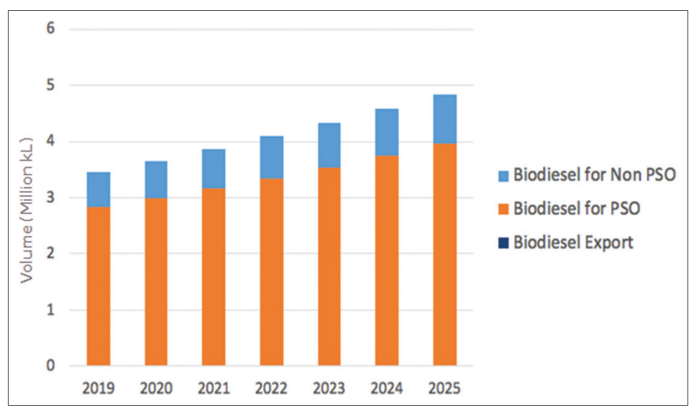


Figure 10 illustrates projection of biodiesel production in Indonesia and its supplied shared. The graph indicates that during the projection period, there is no export of biodiesel. All of produced biodiesel will be fully support domestic demand.

Meanwhile, biodiesel for PSO or biodiesel for blending will be blended with diesel oil with certain percentages, as given in Table 2. The projection of blended biodiesel is given in Table 3. It is also showing that blending shared of biodiesel still could not reach the target.

4.3. Projection of Blended Biodiesel Production in Indonesia

In order to achieve the optimum utilization of biodiesel in Indonesia, blending mandatory is set by the GOI. This blending

Figure 11: Profil projection of biodiesel production

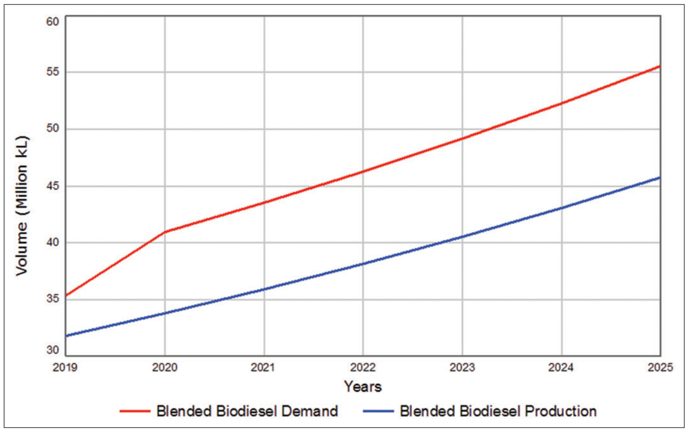


Figure 12: Projection of blended biodiesel production with proposed scenario

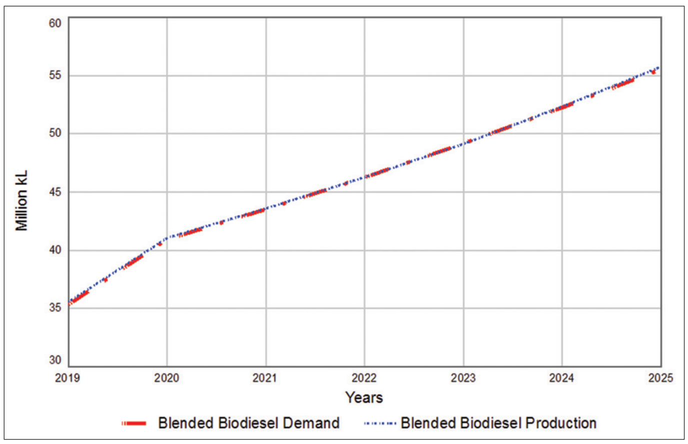


Table 4: Biodiesel demand with proposed scenario

Years	2019	2020	2021	2022	2023	2024
Biodiesel Demand (Million kL)	7.066	12.282	13.056	13.878	14.753	15.682

target will be derived the blended biodiesel demand and Figure 11 shows the projection of blended biodiesel production and demand in Indonesia. In 2020, blended biodiesel demand will reach 40.94 million kL, due to B30 target is pushed, while the production is 33.779 million kL.

It can be seen from the graph that blended biodiesel production could not reach the demand and it needs significant amount of produced biodiesel. Therefore, some strategies are needed in order to balance the supply demand of blended biodiesel and the mandatory blending target can be achieved.

4.4. Policy Scenarios of Increasing Biodiesel production

Conceptual model, on Figure 4, shows that there 3 independent variables as the input scenario of the model; palm oil plantation land, palm oil productivity and CPO shared and 1 output indicator; biodiesel production. Therefore, these variables will be adjusted to get the desired output.

Simulations give the exact value of those variables in order to have a balanced blended biodiesel supply and demand in Indonesia, with these proposed scenarios:

- Increasing palm oil cultivation land for small-holding land from 5% per year to 6.3%, while for state-owner land from 2% per year to 3.2% and for private-owner land from 5% to 6.5%, starting from 2019. Nevertheless, considering the time delay for plantation, these adjustment growth rates will be optimized at least 3 years after cultivation or in 2022;
- Increasing palm oil productivity from 12.26 ton/ha to 12.54 ton/ha;
- Reducing refined CPO shared from 76-65% in 2019 and will be 54% in 2020, which means to reduce refined CPO export from 52.07% per year to 44.57% in 2019 and will reach 38.78% per year in 2020.

Figure 12 reveals the projection of blended biodiesel supply and demand with new scenario from 2019 to 2025. The figure indicates that the supply now reaches the demand. Thus, the mandatory blending target is achieved and diesel oil import is reduced to 7.16-9.82 million kL per year starting from 2020.

The proposed scenario will affect the biodiesel production system in Indonesia and the research shows the current demand of biodiesel for blending in Table 4. If installed capacity of biodiesel in Indonesia is 11.547 in 2017 (Table 1), therefore in 2020, there should be expanding capacity of biodiesel refineries, either by constructing new plants or increasing capacity of existing plants.

5. CONCLUSION

The research simulation shows that in order to meet blended biodiesel demand according to mandatory target, some policy scenarios are needed to conduct. Palm oil cultivation land should be increased to 6.3% for small-holding land, 3.2% for state-owner land and 6.5% for private-owner land, but considering the time delay of plantation, these growth rates will be effective in 2022. Meanwhile, palm oil productivity will be increased to 12.54 ton/ha and refined CPO shared will decrease to 0.6541 in 2019 and 0.5691 in 2020 or pressing the refined CPO export to 44.57% in 2019 and 38.78% starting in 2020. This scenario will meet B30 mandate and will reduce diesel oil import to 7.16-9.82 million kL per year. Biodiesel refineries capacity should be expanded, either by constructing new plants or increasing capacity of existing plants in 2020.

The most influenced variable of blended biodiesel production is refined CPO shared, because this variable is directly related to biodiesel production, therefore the GOI should consider to make refined CPO export limitation policy in order to achieve their biodiesel mandatory blending and reduced diesel oil import.

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