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# Scenario Analysis of Indonesian Biodiesel Policy for Reducing GHG Using System Dynamics

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***Abstract.*** *The issue of renewable energy development has become a major issue in many countries in the context of efforts to reduce the impact of global warming and climate change. Indonesia as the biggest CPO producing country certainly has enormous potential to develop biodiesel as a type of renewable energy CPO producing country certainly has enormous potential to develop biodiesel as a type of renewable energy. A system dynamics model was developed and applied to asses several scenarios in order to generate the appropriate policy of biodiesel for reduce the need of diesel import and CO2 emissions produced by burning fossil fuels. The system dynamics models contain Five sub-systems, including biodiesel demand, biodiesel production, Co2 emission, diesel production and diesel import submodel. Simulation of the current biodiesel policy in Indonesia showed that the Indonesian government support is urgently required to increase the adoption of the use of biodiesel as a renewable energy, as well as of the incentives and mandatory policy. The result of this study showed that increasing of biodiesel incentives and mandatory policies can significantly reduce the need of diesel import and the result of carbon emissions.*

***Keywords****: System Dynamics; Biodiesel; policy; Renewable Energy; Co2 emission*

## I. INTRODUCTION

Climate change and global warming have various negative impacts on various aspects of human life such as extreme weather, damage to ecosystems, disruption of food supplies, and various other impacts (Abokyi, Appiah-Konadu, Abokyi, & Oteng-Abayie, 2019). (Greenhouse gases (GHG) are known to be the main cause of climate change, with carbon dioxide (CO2) as the biggest contributor to this problem (U.S. EPA Office of Solid Waste and Emergency Response, 2009). The main source of CO2 emissions comes from the combustion of fossil fuels which are used to produce energy needed to support human life activities such as transportation, industry, and electricity generation (U.S. EPA Office of Solid Waste and Emergency Response, 2009; Yee et al., 2019).

Until the recent year, national energy consumption in Indonesia is still dominated by fossil fuels as the main energy source, with a total of around 62.87% (Indonesian Ministry of Energy and Mineral Resources, 2021). Furthermore, the transportation sector has the highest proportion of national energy consumption, around 43.87% of the total energy demand (Adi, 2019; Indonesian Ministry of Energy and Mineral Resources, 2021). Total greenhouse gas emissions generated from the energy sector in Indonesia from 2000-2013 have increased from 252 million tonnes of CO2 equivalent to 476 million tonnes of CO2 equivalent, or an average increase of about 5% per year ((MEMR), 2015). However, in terms of energy demand (sectoral and generating) in the same period, it only increased by around 3.7% per year ((MEMR), 2015), so it can be seen that the

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rate of increase in CO2 emissions produced was relatively higher than the increase. demand and national energy needs.

The use of renewable energy is very important to solve the problem of CO2 emissions that occur (Ali et al., 2020; Demirbas, 2009). Biodiesel is a type of renewable energy source that has very good potential to be developed because this energy source comes from animal fats or plant oils that can be renewed in a sustainable manner. This energy source can be a mixture of fossil fuels used in diesel engines or vehicles (Živković et al., 2017).

The Indonesian government has also made various efforts to reduce carbon emissions, one of which is by mandating the expansion of the use of biodiesel fuel by 20 percent or known as B20 for Non Public Service Obligation vehicles which is said to contribute to reducing carbon emissions by 6 to 9 million tons of CO2 per year compared to with the use of pure diesel (Forestry, 2017; Indonesian Ministry of Energy and Mineral Resources, 2015). This is also in line with research conducted by Tan et al (2019). which states that the use of a mixture of biodiesel in diesel fuel has the potential to significantly reduce the resulting carbon emissions.

In addition to reducing the potential for carbon emissions, the mandatory biodiesel policy also has several other objectives, including reducing diesel imports and increasing demand for palm oil in Indonesia, whose production volume always increases every year. In addition, the use of biodiesel also has a fairly good impact on economic aspects(Hasan & Rahman, 2017).

Various studies have been carried out in an effort to reduce the amount of existing carbon emissions. Du et al (2018) has modeled 8 sub-models (socio-economic, primary, secondary, and tertiary industries, transportation, housing, waste disposal, and electricity generation) with their influence on trends in carbon emissions produced using system dynamics approach which then produces output in the form of scenarios that can be carried out in an effort to reduce carbon emissions in the city of Shanghai. Hidayatno, Destyanto, & Fadhil (2019) researched and created models regarding the effect of e-commerce growth on increasing carbon emissions in Jakarta using a system dynamics approach. Rusiawan, Tjiptoherijanto, Suganda, & Darmajanti (2015) also conducted research that discusses the relationship between Jakarta's economic growth and carbon emissions produced through a system dynamics approach, where this research covers economic and environmental aspects, and produces a scenario output of policies to reduce carbon emissions that happened. Aldhaidhawi, Chiriac, Bădescu, Descombes, & Podevin (2017) Comparing the performance and characteristics between fossil diesel and biodiesel b20, This study shows that in general, the use of biodiesel b20 can reduce the potential for carbon emissions produced by pure diesel.

However, although the use of biodiesel is considered to reduce the results of carbon emissions generated by the use of fossil fuels, it turns out that one of the raw materials for biodiesel, namely palm oil, also causes problems related to carbon emissions as well. In research conducted by Dohong, Abdul, & Dargusch (2018), it is clear that the carbon emissions produced by developing oil palm land on peatlands in Kalimantan are quite high. The results of this study indicate that the carbon emissions produced by planting oil palm on peatlands are quite high, namely around 133 to 310 megatons of carbon dioxide. The research that conducted by Yee et al (2019) also stated the same thing, that the palm oil industry is one of the largest emitters of greenhouse gases. These emissions are generated from the accumulation of various processes that occur from upstream to downstream, including changes in land use, cultivation and harvesting processes, transportation, processing in factories, to the waste management process. In the palm oil processing industry, most carbon emissions are generated by palm oil processing waste, which is then followed by diesel consumption and water use (Farhana, Ab, & Hashim, 2019). In addition, the high price of CPO as the main raw material for biodiesel makes biodiesel production costs relatively higher than the cost of producing fossil fuels so that a policy is needed to make biodiesel

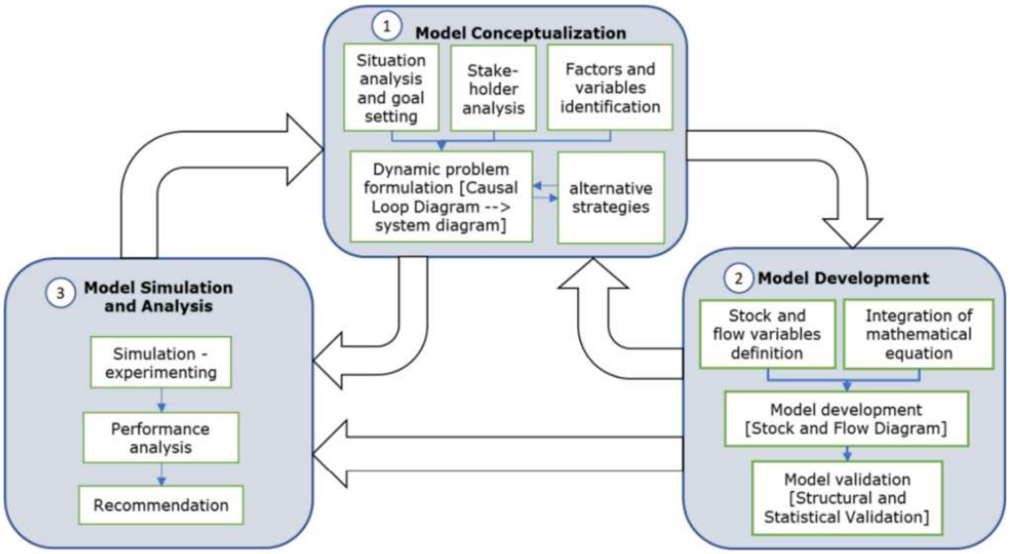


**Figure 1.** Development of a model based on the methodology developed by Sterman (2000)

competitive with fossil fuels in front of consumers.

Based on the problems faced and several previous studies, it is important to do the research that comprehensively discusses the effect of the use and production of biodiesel to replace the use of fossil fuels on carbon emissions produced in Indonesia. Therefore, this study will discuss the dynamic system modeling of policies and trends in the use of biodiesel in Indonesia and its effect on the resulting carbon emissions.

This research will use a system dynamic method to see and model the relationship and influence between variables and we can simulate the model and then carry out policy scenarios in order to reduce carbon emissions that occur. In addition, this research is also important to do considering that currently, the Indonesian government is quite aggressively applying the use of B30 biodiesel as a substitute for fossil fuels, so this research is needed to see whether the implementation of policies to produce and campaign for the use of biodiesel has a good or bad impact. for the environment, especially the resulting carbon emissions.

## II. METHODOLOGY

In the initial process of building a dynamic system simulation model in this study, mental data is needed to be used as a basis for mapping the structure of the biodiesel adoption system in Indonesia, what factors influence biodiesel adoption in Indonesia, how does biodiesel adoption affect CO2 emissions. generated, as well as what interventions can be done in achieving the goals of the problem owner. This metal data is obtained from various literary sources such as research journals, official government websites, as well as the annual work report of the ministry of energy and mineral resources. Furthermore, the mental data that has been collected becomes a frame of reference in determining what numerical data is needed.

To model the structure of the biodiesel adoption system in Indonesia, several reference models are used in previous research as a basis for mapping the system structure that occurs in Indonesia.

One of the models that can be used as a reference for studying the structure of biodiesel development is the Causal Loop Diagram which is produced from a study conducted by [20] entitled Sustainability assessment to support governmental biodiesel policy in Colombia: A system dynamics model. This study aims to assess the sustainability aspects of the mandatory biodiesel policy in Colombia using a dynamic systems simulation approach.

As a simulation method, the system dynamic simulation is derived from systems thinking that is widely used as a tool in management and planning Kamyabi, Moazzez, & Husseinzadeh Kashan (2022). This method is opposite to linear thinking which has an assumption that the events

and mechanisms leading to these events remain unchanged over time. Meanwhile, systems thinking or System dynamics is based on the feedback processes theory and used as an approach to understanding the complex systems' behavior over time (A. Ghosh, 2015; Forrester, 1994; Pierreval, Bruniaux, & Caux, 2007; Sterman, 2000).

# III. RESULT

Indonesian Biodiesel Adoption System Diagram and Causal Loop Diagram: A system diagram is a tool that can be used to describe a system and problems comprehensively (Ramdhani & Setiawan, 2022; Tul Munikhah, Ramdhani, Pratama, & Arini, 2022). The system diagram consists of several parts, including Problem Owner, Goals of Problem Owner, Policy Intervention, Input, Output, and Stakeholder's Influence(Arini et al., 2024; Tul Munikhah et al., 2022). Figure 2 is a diagram of the system for biodiesel adoption in Indonesia.

Based on the system diagram, it can be seen that the problem owner in the biodiesel adoption system in Indonesia is the Ministry of Energy and Mineral Resources which has several objectives including increasing the adoption of biodiesel use in Indonesia, reducing petroleum imports, and reducing the resulting carbon emissions. The policy interventions that can be carried out by the Ministry of Energy and Mineral Resources as the owner of the problem include conducting campaigns to increase the use of biodiesel by the community, investing in biodiesel production facilities, providing incentives or subsidies to the biodiesel program in Indonesia, and implementing mandatory policies on the use of biodiesel in the sector using a diesel engine. These policy interventions can be carried out on several input variables, namely the biodiesel price variable, the biodiesel campaign, and the biodiesel production capacity. The external factors that affect the biodiesel adoption system in Indonesia are the price of petroleum and the price of crude oil or CPO (Crude Palm Oil). Apart from the Ministry of Energy and Mineral Resources which has the role of the problem owner, the biodiesel adoption system in Indonesia also has stakeholders or other takeholders who have an interest and influence on the system, either directly or indirectly. The stakeholders are the Ministry of Agriculture, the Ministry of Environment and Forestry, the Ministry

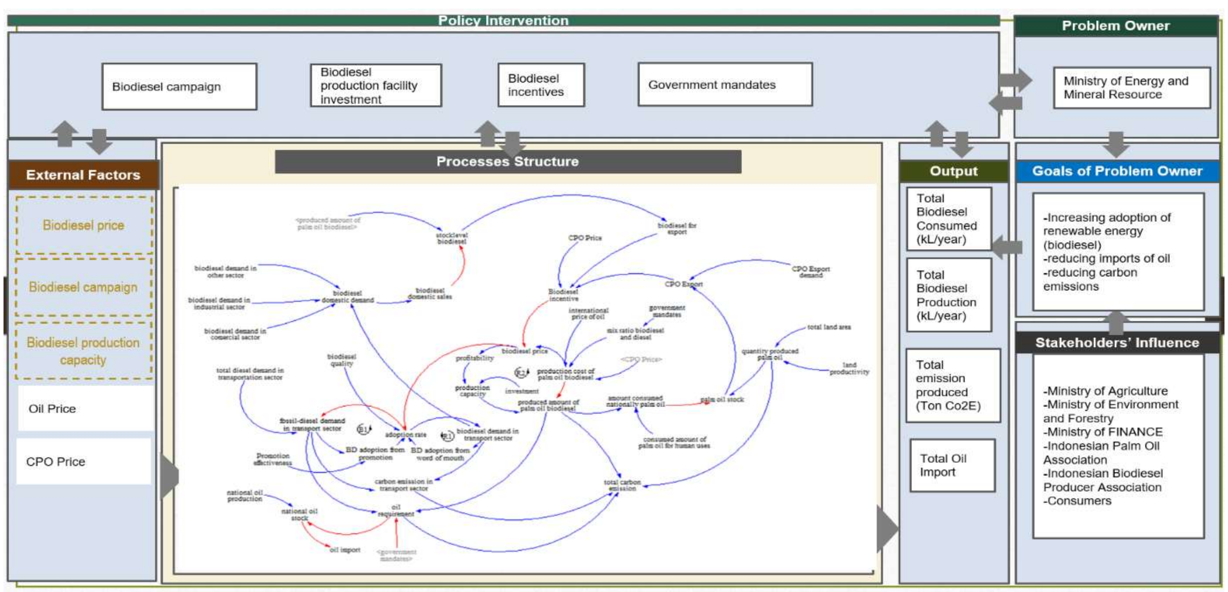


**Figure 2.** System Diagram of Biodiesel Adoption and Policy in Indonesia

**Table 1.** Actor Analysis

| Actor | Roles and Responsibility | Problem Perception | Objectives |
|---|---|---|---|
| Ministry of Energy and Mineral Resource | establish rules and guidelines for the manufacture and use of biodiesel | The goal of using more than 23% of renewable energy by 2025 is still far off | Create biodiesel to improve the use of renewable energy sources. |
| Ministry of Agriculture | issue policies and regulations regarding the palm oil development | Biodiesel development risks to reducing the land for other agricultural commodities | Develop the sustainability and Increase the productivity of palm oil land |
| Ministry of Environment and Forestry | issue policies and regulations regarding the environmental impact standards in palm oil development | Palm oil development leads to deforestation | Develop the sustainability and environmentally friendly of palm oil development |
| Ministry of Finance | Issue policies and regulations regarding the biodiesel development budget | Development of biodiesel has the potential to save foreign exchange and increase job opportunities, but also increase the budget for subsidies | developing biodiesel in order to increase export and foreign exchange |
| Indonesian Palm Oil Association | Supply the palm oil as raw material of biodiesel | Development of biodiesel can increase domestic consumption and stabilize prices of palm oil | Encourage the biodiesel development to increase the demand of palm oil |
| Indonesian Biodiesel Producer Association | Create the supply of biodiesel | Biodiesel production costs are relatively higher than fossil diesel production costs | Encourage the biodiesel development and utilization to obtain higher profit |
| Consumers | Create the demand of biodiesel | Customers fear that the use of biodiesel will shorten the life of the vehicle engine | Obtain good quality fuel with affordable price |

of Finance, the Indonesian Palm Oil Association (GAPKI), and the Association of

Biodiesel Producers (Aprobi). Each of these stakeholders certainly has different roles and responsibilities, interests, and perceptions of problems.

After mapping the structure of the biodiesel adoption system in Indonesia, a Causal Loop Diagram (CLD) was developed, which is a tool to represent the causal relationship between variables that influence each other in the biodiesel adoption system in Indonesia, where the development of CLD refers to the mental model has been collected. The CLD model developed in this study can be seen in Figure 3. The following Table 1 describes the analysis of actors / stakeholders involved in the biodiesel adoption system in Indonesia.

After collecting the required data, the next step is to develop a simulation model in the form of a Stock and Flow Diagram (SFD) to translate mental data and the conceptual model that has been developed into a simulation model that is quantitative with the input of numerical data that has been obtained. previous. As for the development of SFD in this study, there are five submodels, namely biodiesel demand submodel, biodiesel production submodel, Co2 emission submodel, diesel production and import submodel, and CPO production submodel. Figure 4 shows the SFD model that has been developed in combination from the five existing submodels.

### Model Verification and Validation

The SFD model in the biodiesel adoption system in Indonesia is made and developed with the help of Powersim 10 software. Model

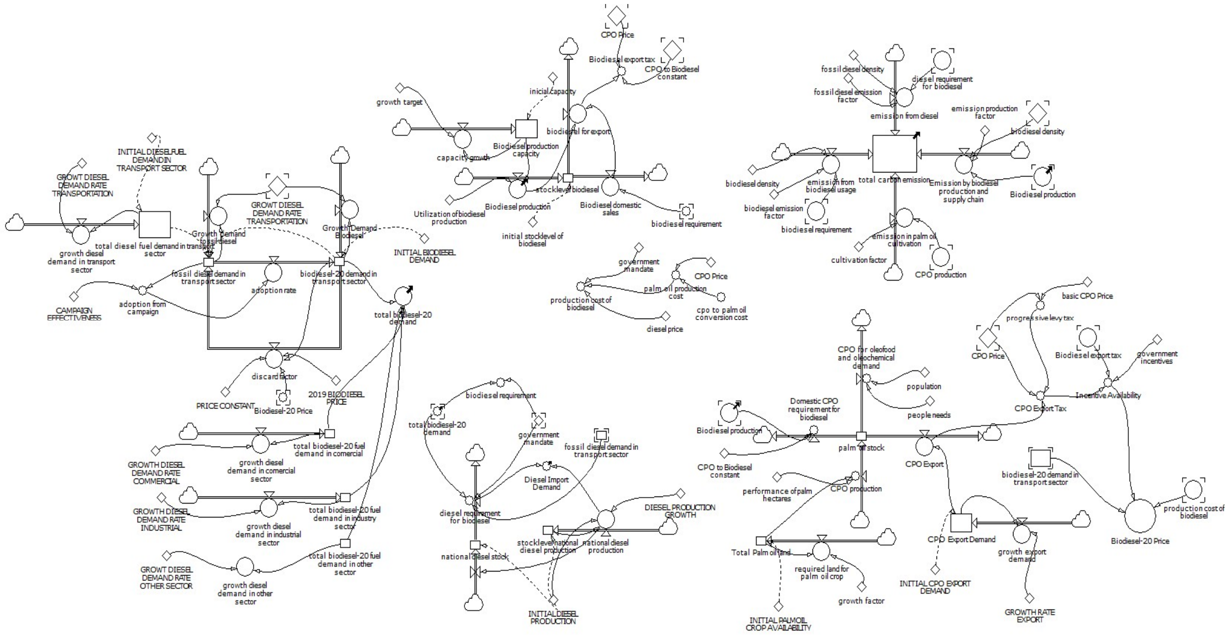

**Figure 4.** Stock and Flow Diagram of Biodiesel Adoption and Policy in Indonesia

verification is carried out to ensure whether the model made is in accordance with the modeler's will or not. In this case, verification is carried out to see whether the simulation runs smoothly or not. In this study, the model has been verified by Powersim 10 software because the software has a feature to identify errors and unit consistency in the model. Meanwhile, model validation is done to assess whether the model that has been created can provide a true picture of a system and the resulting output.

The validity test consists of the adequacy of the limits, the structural assessment test, the dimensional consistency test, the historical data test, the extreme conditions test and errors in integration. The description of each validity test can be seen in the sections below.

**Adequacy of Limits.** The purpose of this simulation model is to simulate various policy alternatives to increase the adoption of biodiesel in Indonesia and contribute to reducing carbon emissions that occur in Indonesia. In this case, the limits set by the author are aspects related to the amount of biodiesel use and carbon emissions produced by referring to the system structure limitations that have been made and discussed in the discussion of the system diagram in Figure 2.

**Structure Assessment Test.** The structure assessment test is a test used to determine whether the model structure is in accordance with the CLD conceptual model. The model that has been created has a system-relevant logic structure as described in the CLD in the previous explanation. The model has been adjusted with reference to the conceptual model and each loop has been traced.

**Dimensional Consistency Test.** The dimensional consistency test is a test to ensure the consistency of the unit in the SFD model that has been made. At this testing stage, Powersim Studio 10 software has a feature that detects unconsistency in the unit which will be indicated by a red mark on the variable. The results of SFD processing using powersim have no red mark or fence on the model, so the dimensional consistency test is said to be valid.

**Test the validity of behavior through historical data**. Behavioral validation aims to ascertain whether the model can run and produce behavior that matches the data on the real system or not. This behavior validation is carried out on the key variables which are the main indicators of the model in this research. The variables tested were the biodiesel consumption variable in certain years. The following is a comparison of the results of the model behavior to actual data in the form of data tables as well as system behavior charts and simulations.

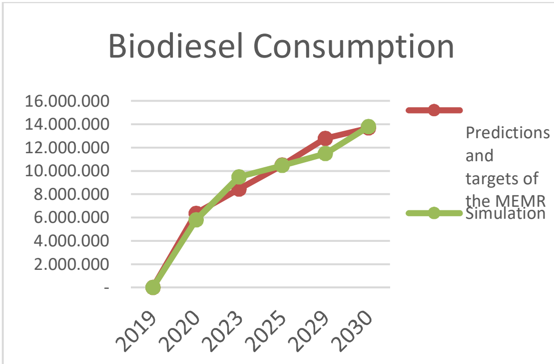


**Figure 5.** Comparison of Model Behavior Against Real Systems

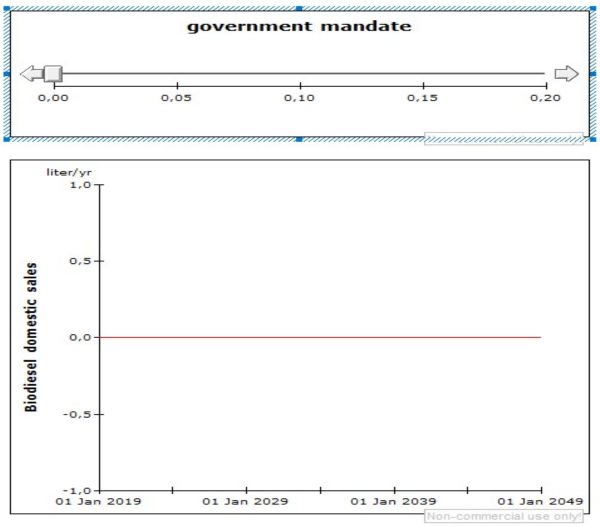


**Figure 6.** Test Results for Extreme Conditions

**Extreme Condition Test.** An extreme condition test is carried out to see the model's behavior when given extreme conditions. In this simulation model model of biodiesel adoption system in Indonesia, testing of the biodiesel domestic sales variable is carried out if extreme conditions are given to the government mandate variable. The dynamic hypothesis is that if the government mandate is set to 0, the domestic sales of biodiesel will also produce the number 0. After testing the simulation model, the results are as shown in Figure 6.

The results obtained after testing are in accordance with the dynamic hypothesis, namely when the government mandate is set to 0, the domestic biodiesel sales will also produce the number 0, so it can be concluded that this model is valid at this testing stage.

**Error in Integration test**. This test is a step to test the sensitivity of the simulation results to the time step used. This test is carried out on the total biodiesel-20 demand variable by comparing the output at a time step of 1 year against a time step of 0.5 years. The test results can be seen in the following figure.

Based on the results of the tests that have been carried out, it is known that the output on the total biodiesel-20 demand variable which is simulated at two different timesteps has results that are not much different each another.

### Scenario and Alternative Design

At the stage of designing scenarios and policy alternatives, the first step is to determine alternative policy options that will be simulated. In this study, the policy variables that will be used in the alternative design process are the government incentive variable and the mandatory use of biodiesel according to the policy intervention variable that has been described in the discussion of the system diagram in the previous chapter. Each policy variable has 3 alternative levels to be formulated into an alternative policy. The indicators used to measure these policy alternatives are the total biodiesel

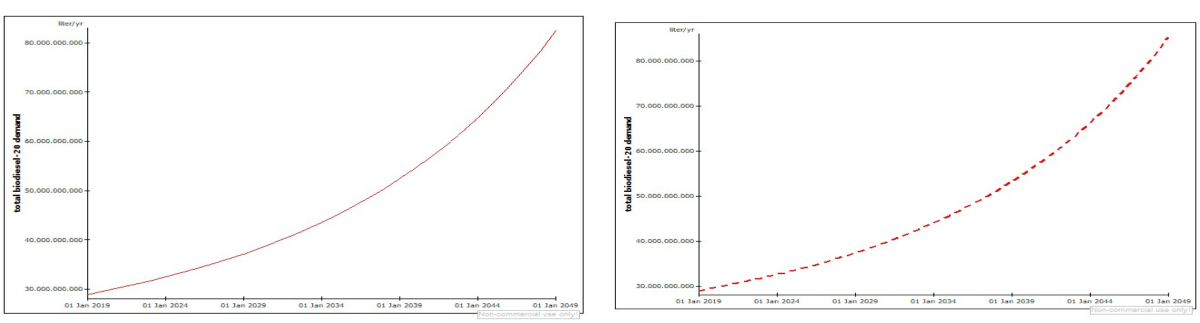


**Figure 7.** variable behavior of total biodiesel-20 demand with a timestep of 1 and 0.5 years

consumption variable, carbon emission reduction, and the diesel import rate. Table 2 shows the combination of alternative policies that were designed.

**Table 2.** Alternative variables and indicators

| No | Variabel alternatives | Variabel indicator |
|---|---|---|
| 1 | Government incentives | Total biodiesel consumption |
| 2 | Government Mandatory use of biodiesel | CO2 emission reduction |
| 3 | | Total solar import |

After the policy alternatives are designed, the next step is to design scenario factors to assess the consistency and results of each of these policy alternatives against various conditions that may occur. The external variables chosen as variables in this scenario are the variable CPO prices and diesel prices. Table 4 shows the scenario factors designed in this study.

**Table 3.** Design Alternative Policy

| Alternatives | Incentives | Mandatory |
|---|---|---|
| baseline | 3,6T | B20 |
| 1 | 2,7T | B40 |
| 2 | 2,7T | B50 |
| 3 | 2,7T | B100 |
| 4 | 4,5T | B40 |
| 5 | 4,5T | B50 |
| 6 | 4,5T | B100 |
| 7 | 5,4T | B40 |
| 8 | 5,4T | B50 |
| 9 | 5,4T | B100 |

**Table 4.** Design of scenario factors

| Scenario | CPO Price | Dieselfuel Price |
|---|---|---|
| 1 | 1255 usd/ton | 6690 idr/ton |
| 2 | 1255 usd/ton | 2801 idr/ton |
| 3 | 602 usd/ton | 6690 idr/ton |
| 4 | 602 usd/ton | 2801 idr/ton |

**Results and Scenario Analysis**

**Policy Proposals and the selection of alternatives**

Based on the results of scenario simulations and analyzes that have been carried out, it is known that there are several alternatives that have similar values such as alternative 1 with alternatives 4 and 7, alternative 2 with alternatives

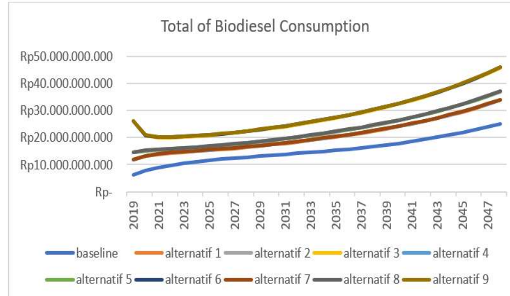


**Figure 8.** Comparison of pure biodiesel consumption among alternatives

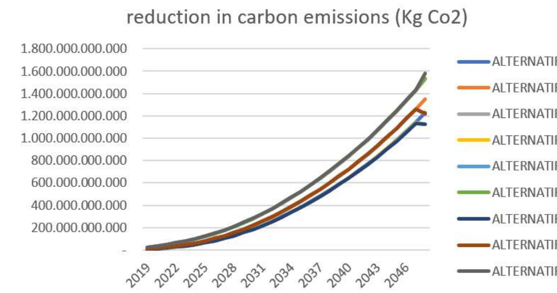


**Figure 9.** Comparison of the resulting reduction in carbon emissions between alternatives

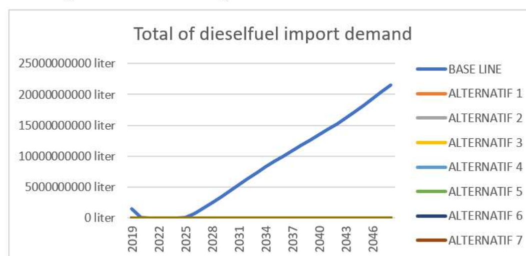


**Figure 10**. Comparison of total diesel import needs among alternatives

5 and 8, and alternative 3 with alternatives 6 and 9. This happens because the effect of government incentives on biodiesel adoption is not too significant because the value is too small. In the indicator of total biodiesel consumption, it is known that alternative 9 where the mandatory B100 policy is implemented and an incentive of 5.4 trillion rupiah always has the highest yield in all scenarios. This is due to the high composition of pure biodiesel in fuel so that the CPO export tax is used to subsidize the selling price of biodiesel so that the adoption of its use can continue to increase. Furthermore, alternative 9 always gets the highest carbon emission

reduction results in each scenario, this proves that the higher the use of biodiesel compared to fossil energy will reduce the resulting carbon emissions. Meanwhile, based on the results of running simulations on the indicator of total diesel imports, it shows that all policy alternatives other than the baseline model will eliminate Indonesia's dependence on diesel needs in meeting diesel energy consumption needs. This is because domestic diesel production can meet the national demand for diesel fuel if the mandatory minimum b40 policy is implemented. However, although alternative 9 always has the highest value on each indicator, alternative 3 can be considered to be taken because with a lower incentive amount of IDR 2.7 trillion, it produces results whose value is not significantly different from alternative 9.

Based on this, the authors provide policy recommendations for the Government of Indonesia, in this case the Ministry of Energy and Mineral Resources as the problem owner to take alternative 3 as a policy where the government implements a mandatory policy on the use of B100 biodiesel with a total incentive of 2.7 trillion rupiah.

## IV. Conclusion

Based on the research that has been done, the following conclusions can be drawn:

1. Implementation of mandatory policies for the use of biodiesel can significantly reduce the resulting carbon emissions.
2. The current implementation of the mandatory b20 policy has resulted in a fairly good reduction in carbon emissions but can still be improved, and the policy still requires imports of diesel in its implementation.
3. There are many factors that significantly influence the biodiesel adoption system in Indonesia, such as the price of biodiesel raw materials, mandatory policies, and subsidies for biodiesel.
4. The dynamic system simulation model being developed is used to explore various policies in increasing the adoption of biodiesel in Indonesia.
5. The author designs 9 policy alternatives that are simulated in 4 scenarios to assess the total use of biodiesel, reduce carbon emissions, and the need for diesel imports.

Based on the testing of alternatives that have been carried out, alternative 3 is the best alternative that can be taken where the alternative presents a mandatory policy of using B100 biodiesel and an incentive of 2.7 trillion rupiah.

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