Sustainable supply chain design for waste cooking oil-based biodiesel in bogor using dynamic system approach

A D Syahdan[1], Y Arkeman [1,2], H Wijaya[1,2]

[1] Department of Agroindustrial Technology, Bogor Agricultural University, Bogor, Indonesia

[2] Surfactant and Bioenergy Research Center, Bogor Agricultural University, Bogor, Indonesia

Email: yandra_ipb@yahoo.com

Abstract. Biodiesel is one of the alternative fuels that are environmentally friendly. Besides palm oil, biodiesel can also be produced from waste cooking oil. Since 2007, the government of Bogor has been utilizing waste cooking oil into biodiesel for use as Transpakuan bus' fuel. However, in practice, the amount of waste cooking oil supplied is never sufficient the needs of fuel of 30 units Transpakuan bus. The main objective of this research is to analyze the availability of waste cooking oil that will be converted into biodiesel within the next ten years as well as providing policy advice to support the program. The method used is a dynamic system that is followed by simulation of multiple scenarios that have been defined. The system is divided into three subsystems, namely supply subsystem, demand subsystem, and production subsystem. The results showed that the current system is not able to guarantee the sustainability of the supply chain of waste cooking oil as a raw material of biodiesel. From some of the scenarios tested can be concluded that biodiesel needs would increase in line with the trend of the use of environmentally friendly fuels. It takes a new system and a new policy relating to the biodiesel supply chain. Policy suggestions that can be proposed from this research is to increase supplier participation, objectify the program of converting angkot into Transpakuan bus, and support the development of biodiesel industry.

1. Introduction

One of the most potential renewable energy to be exploited in Indonesia is biodiesel. Biodiesel is a biofuel or fuel made from vegetable oils, either it is fresh or a leftover frying results through esterification and transesterification stages. The government has targeted the use of biodiesel as a fuel mixture for industry, transportation, power generaton, and commercial respectively by 30% in 2025. While in Blueprint Pengelolaan Energi Nasional 2006-2025, the cumulative capacity of biodiesel is expected to reach 222.000 barrels per day [1]. According *to Kebijakan Energi Nasional (KEN)*, biodiesel supply in 2014-2050 will grow in an average of 9,7% per year [2]. The use of palm oil as the raw material for bodiesel is more focused on the food sector. So, the raw materials of biodiesel is diverted to waste cooking oil as an alternative. Real form of the use of biodiesel as an alternative fuel has been carried out by the government of Bogor city. It has launched a program of utilizaton of waste cooking oil into biodiesel used as fuel of Transpakuan, one of the public transportation in Bogor.

This program was cretaed as a real contribution from Bogor who are members of International Climate Environmental Initiative (ICLEI) as an effort to prevent global warming. The number of public transportation vehicle and transport systems that are uncontrolled in Bogor making an alarming increase of air pollution. It happened because of the increased activity and mobility of people in and around Bogor. According to Badan Pengelolaan Lingkungan Hidup (BPLH) Bogor in 2012, 16.600 liters of waste cooking oil can be converted to 13.280 liters of biodiesel per year [3]. Waste cooking oil obtained from citizens, schools, restaurants, hotels, hospitals, and food processing industry [4]. Waste cooking oil is the cooking oil that have been used for two or three times. It has a bad impact to human health if it is used for more than three times. So, in addition to reducing vehicle pollution , the use of waste cooking oil as a raw material for biodiesel can also improve food security and establish a healthy lifestyle for the people of Bogor [5].

The process of converting waste cooking oil into biodiesel is done by PT. Bumi Energi Equatorial (PT. BEE). Previous research states that the bussiness run by PT.BEE is not financially feasible assessed from it's NPV, B/C ratio, and Internal Rate of Return (IRR). It is caused by the gap existed between production capacity of the plant and the amount of supply of the waste cooking oil. PT. BEE has 30 tons of production capacity while the raw material's supply is just 2 tons per month. For the success of this program, it required an integrated system that can ensure the sustainability of biodiesel production from raw materials to the the hands of consumers. The system involves many stakeholders with different functions and tasks but have the same goal. Therefore, a good supply chain management is needed so that every stakeholder is able to carry out their duties properly and make a profit from these activities.

2. Metodology

The study begins with a literature study on supply chain and dynamic system. Dynamic system was first introduced by Jay W. Forrester in 1961. The dynamic system is used to describe a complex system in which the variables contained therein are interconnected to one another. The relationship between these variables will generate feedback information that changes over time [6]. A system can be referred to complex and dynamic if it is always changing every time, all the variables in the system are interrelated and influence each other significantly, as well as works based on the feedback between the variables in it [7].

Based on the relationship between the variables, the purpose of the system and the factors that can accelerate or inhibit the process of achieving the goals of the system can be defined. Therefore, the dynamic system is suitable for the formulation of future policy in a complex system that is changing continuously. There are two stages used in the dynamic systems approach, namely Causal Loop Diagram (CLD) or a causal diagram and the Stock and Flow Diagram (SFD) or diagram arrow box. Furthermore, the identification of problems is done by analyzing the existing supply chain condition and interviews with relevant stakeholders. Based on the information obtained, we can determine the scope of issues and stakeholders that will be involved in the model. Restrictions on system is very important because it will affect the model that will be used for system simulation. In addition, the analysis was also conducted to look at the role of each stakeholder along the supply chain. After the system is identified, the variables involved in the system are determined and analyzed how they affect each other.

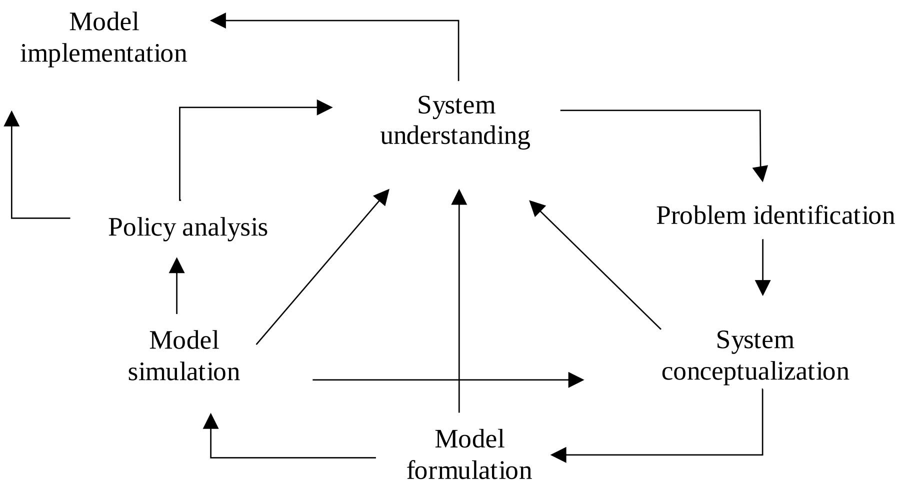

Figure 1. System dynamic approach [8]

The relationship between variables is described by the causal loop diagram. In the causal diagram, the relationship between variables is described by the symbol (+) and (-). The symbol (+) illustrates the proportional relationship between variables, otherwise the symbol (-) illustrates the inverse relationship between variables. Once the causal diagram is formed, the relationship between variables is described qualitatively using a mathematical formulation of the stock and flow diagram. Stock describes the status or condition of a variable at a certain time while the flow indicates the status or the state of variables at certain intervals. Stock is the accumulation of inflow and outfow a variable.

To connect the stock to flow, the type of the variable used is called the auxiliary. By using these three types of variable, relationships between variables in dynamic systems can be better explained [6].

Stock and flow diagrams created with Anylogic 7.3.1 Personal Learning Edition. By using the software, the stage of verification of the model can be done. Verification is required as evidence that the model, which is based secondary data, is technically correct and there is no error at all so it is valid to use. Furthermore, the simulation can be done using Anylogic 7.3.1 Personal Learning Edition based on the scenarios that have been determined for a period of 10 years, namely 2016 as the start time and in 2026 as a stop time.

Model validation is the process of comparison between the output generated by the simulation model with the values contained in the real system. This is done to see if the model is able to represent the real system appropriately [9]. One of the validation methods by comparing the model with real systems (quantitative behavior pattern comparison) is the method of Mean Average Percentage Error (MAPE) [10]. Percentage difference or error between the real system and the model becomes the reference of validation.

3. Result and Discussion

3.1. System Description

Dynamic system modeling is used to describe the relationship between variables that will affect the availability of waste cooking oil as a raw material of biodiesel. Models of dynamic systems that are used are divided into three subsystems, namely supply subsystem, demand subsystems and production subsystem. Supply subsystem consists of supply potential of citizens, the supply of the restaurant, the supply of hotels, the supply of hotels and inns, as well as the supply of school. Demand subsystem consists of a fleet of Transpakuan and mandatory biodiesel blend with diesel yield. While the production subsystem is a biodiesel plant capacity.

Tabel 1. Stakeholders and their needs

No	Stakeholders	Needs
1	BPLH	Absorp all of the potential of waste cooking oil
2	Suppliers	Reward and appreciation
3	Biodiesel plant (PT. BEE)	The sustainability of the raw material and profitt oriented
4	Consumer (PT. PDJT)	Availability of biodiesel

Relationships between variables in the system and how they affect each other can be explained in the causal loop diagram. Feedback between variables is the basis of dynamic system modeling can be done. The availability of waste cooking oil is influenced by the supply of waste cooking oil from citizens, schools, hotels, and hospitals. The greater the number of the supply the more waste cooking oil is available. Total supply of waste cooking oil increase if the number of residents, schools, restaurants, hotels, and hospitals in the city of Bogor was growing too. On the other hand, the increasing demand for biodiesel will reduce the availability of waste cooking oil. Increased demand for biodiesel is caused by the increase of the fleet ofTranspakuan and increase of mandatory biodiesel blend with diesel yield. The increasing demand for biodiesel should be offset by increased factory capacity as a producer of biodiesel. These three factors are influenced by policies of Bogor and national government on the public transport system and the use of renewable energy up to 10 years.

3.2. System Formulation

Based on the causal loop diagram that has been created, the relationship between variables in the system qualitatively described using stock and flow diagram in Anylogic 7.31 PLE software. The relationship between the variables described in a mathematical equation based on several assumptions derived from BPLH, PDJT, and BPS Bogor as follows:

1. Supply of waste cooking oil in the system is limited only from citizens, schools, restaurants, hotels, and hospitals in the city of Bogor.
2. Waste cooking oil that have been collected are given only to BPLH Bogor and biodiesel produced will be sold to one party, PT. PDJT (Perusahaan Daerah Jasa Tansportasi) Bogor.
3. The consumption of cooking oil / capita / year = 7.96 liters / capita / year.
4. The potential of waste cooking oil at every school in the city of Bogor = 50 liters / month.
5. The potential of waste cooking oil at every hotel in the city of Bogor = 2 g / guest / day, 10% of guests ordering food.
6. The restaurant is divided into three categories based on the number of visitors, top (200 visitors / day); medium (100-200 visitors / day); lower (<100 visitors / day). Potential waste cooking oil 5 g / visitors / day.
7. The hospital is divided into three categories based on number of in-patient visits, top (> 12,000 patients / day); medium (4800-12000 patient / day); lower (<4,800 patients / day). Potential waste cooking oil 5 g / patient / day.
8. The density of waste cooking oil is 0.9 kg / liter.
9. The yield of waste cooking oil to the cooking oil = 0.3

10. TransPakuan B20 biodiesel Consumption is 6 liters / day / unit.
11. Bogor City population growth rate is 1.98% per year.
12. The rate of accretion of the school in the city of Bogor is 3.35% per year.
13. The rate of addition of restaurants in the city of Bogor is 20.7% per year.
14. The rate of addition of hotels in the city of Bogor is 3.94% per year.
15. The rate of addition of the hospital in the city of Bogor is 15.3% per year.
16. The rate of increase in the number Transpakuan is 20% per year.
17. The capacity of the plant is 30 tons per month, or 400,000 liters per year.

Mathematical equation that are the main objectives in this model is:

The availability of waste cooking oil = Supply of waste cooking oil – Demand of biodiesel fuel
Supply subsystem defined by the following mathematical equation:

The supply of waste cooking oil = household waste + school waste + hotel waste + restaurant waste + hospital waste
Household waste = total population * potential of waste cooking oil
Total population = 1047922 + dt * population growth rate
Potential of waste cooking oil = cooking oil consumption per capita * waste cooking oil yield
School waste = number of schools * waste cooking oil potential in school
Number of schools = 463 + dt * the growth rate of the number of school
Waste restaurants = number of restaurants * the potential of waste cooking oil in restaurants
Number of restaurants = 224 + dt * the growth rate of the number of restaurants
Hotel waste = Number of hotel * potential of waste cooking oil in hotel
Total hotel = 53 + dt * the growth rate of the number of hotel
Hospital waste = Number of hospital * waste cooking oil potential in hospitals
Number of hospitals = 17 + dt * rate of increase in the number of hospital

Growth rate of population, schools, restaurants, hotels, and hospitals respectively is 1.98%; 3.35%; 20.7%; 3.94%; and 15.3% per year [3, 11, 12]. Data show that all positive growth rate, which means the number of suppliers is always increasing and the potential of waste cooking oil produced is always growing every year. The unit used is a unit / year. While dt is the change in time or a time interval of simulation.

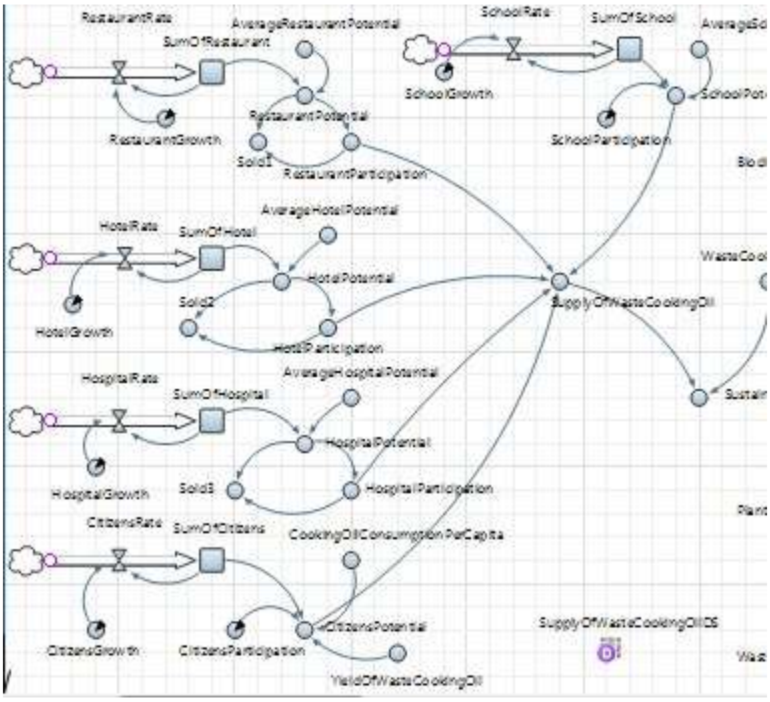

Figure 2. Supply subsystem

Demand subsystem formulated by the following equation:

Demand of waste cooking oil = fuel consumption per unit TransPakuan * mandatory yield * number of fleets * 0.8

The number of fleet = 30 + dt * the growth rate of TransPakuan
Mandatory yield = 0.2 + dt *the growth rate of mandatory yield

The increment of Transpakuan amount and yield of biodiesel blends used will increase the demand of waste cooking oil. It depends on the policy implemented by the central government and local government in line with the developments taking place within the next 10 years.

Production subsystem
Biodiesel production activities done by only one plant, namely PT. Bumi Energi Equatorial (PT. BEE). PT. BEE has a production capacity of 30 tons per month, but the realization of the supply of waste cooking oil that there were only 2 tons per month [13]. Production subsystem defined by the following mathematical equation:

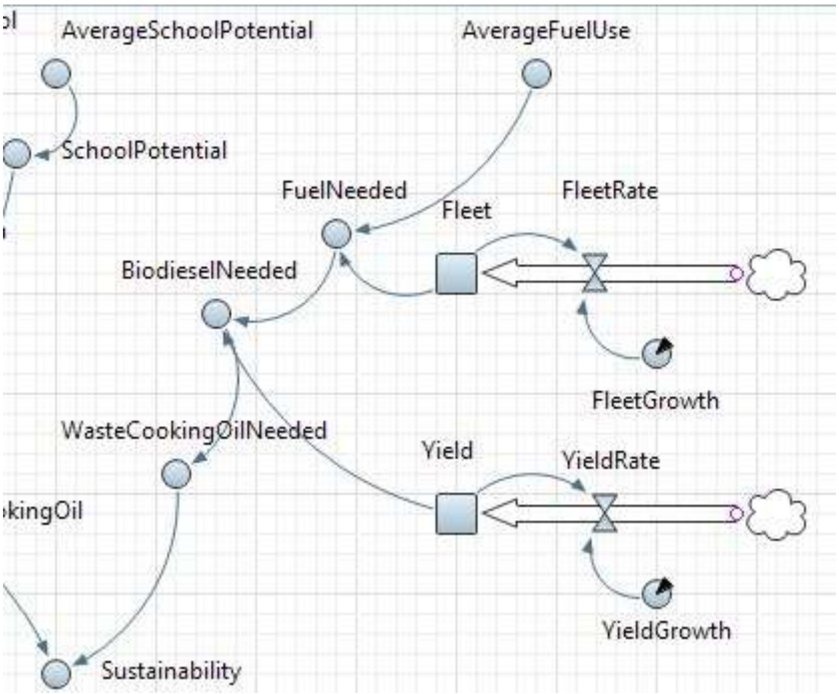

Figure 3. Demand Subsystem

The capacity of the plant = 400,000 + dt * growth rate of plant capacity

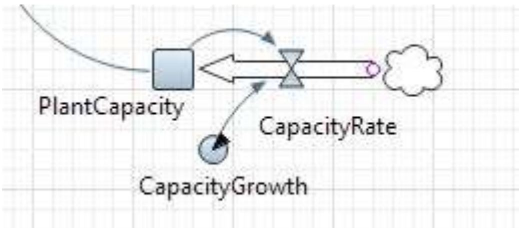

Figure 4. Production subsystem

3.3. Scenarios

Model of availability of waste cooking oil for the next 10 years is analyzed in accordance with the possible conditions and situations that may occur in this period. Selection of scenarios adapted to the stakeholders' targets who influence the system during the simulation period. Each simulation scenarios show different results. These results are used as a reference to answer the research objectives that have been defined. The scenarios used in this study include:

3.3.1. Scenario without alteration / Business as Usual

In this scenario, the simulation is done in accordance with the current state without any change in the system variables. Supplier participation by 0.4%, the rate of Transpakuan, the rate of mandatory yield, and the rate of increase in the production capacity of each is 0. The simulation results show that the supply of waste cooking oil is not able to cover the demand for biodiesel up to 10 years into the future.

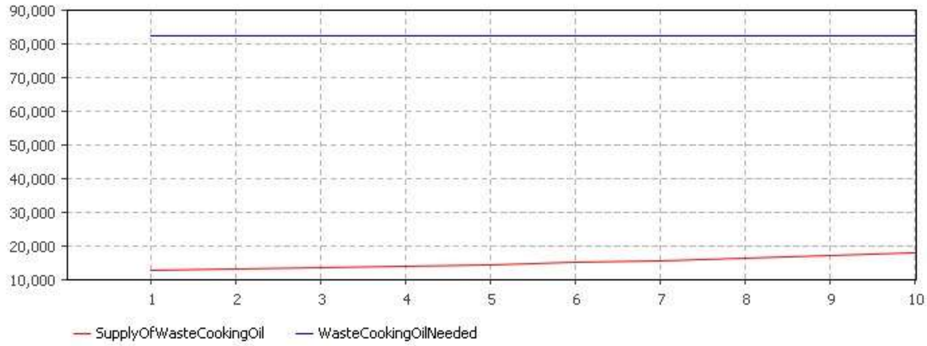

Figure 5. Scenario 1 result

3.3.2. Enhancement of supplier participation and mandatory biodiesel yield scenario

In this scenario, the participation of suppliers increased to 10% and the growth rate of mandatory biodiesel yield increased to 12.5% per year. The simulation results show that during the next 10 years of supply chain waste cooking oil into biodiesel can be assured of sustainability.

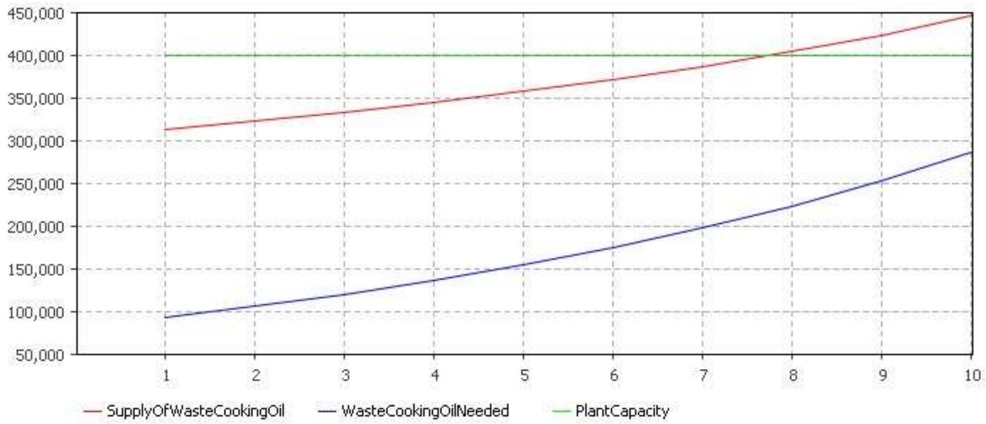

Figure 6. Scenario 2 result

3.3.3. Scenario an increase in supplier participation and the rate of increase in the bus fleet Transpakuan

In this scenario, the situation is assumed that the participation rate is 50% per year, the growth rate of mandatory biodiesel yield remained 12.5% per year, an increase in the growth rate of Transpakuan to 10% per year, and an increase in production capacity by 10% per year. It refers to the target of PT. PDJT Bogor to operate 7 Transpakuan bus corridors in Bogor. The simulation results also indicate that the supply of waste cooking oil can meet the demand for biodiesel from first year to the tenth year. Although there is a change in the growth rate of Transpakuan to 10% per year, but it can be handled by the increase of supplier participation to 50%.

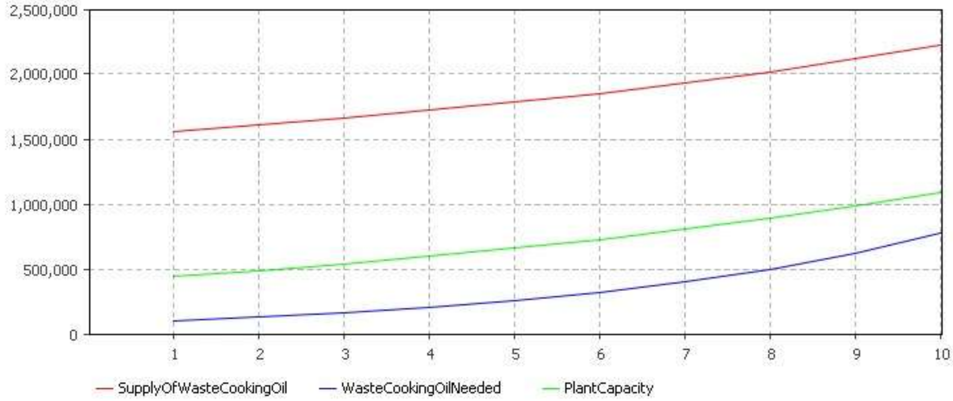

Figure 7. Scenario result

3.4. Model Validation

Model validation conducted by comparing the results of the simulation model of the real system. The samples are population and number of schools in the city of Bogor. The beginning of the simulation adjusted to the start time in simulation. It is 2010 for a variable number of people and 2011 for the number of schools in the city of Bogor. Both were calculated until 2015. In the validation of Bogor citizens, real system shows the value respectively from 2010 to 2015 was 950.334, 987.315, 1.004.831, 1.013.019, 1.030.720, and 1.047.922. Population growth rate per year reaches 1.98%. As for the validation of the number of schools in the city of Bogor, real system respectively from the years 2011-2015 shows the the value of 407 units, 448 units, 452 units, 453 units and 463 units. Growth rates of the number of schools in the city of Bogor per year is 3.35%. The datas of population and number of schools in the city of Bogor obtained from BPS Bogor through Bogor Dalam Angka (BDA) in 2015 [12]. Both variables tested show results of the calculation of MAPE by 0.8% for the population the city of Bogor and 2.4% for the number of schools in the city of Bogor. The results show that the model is able to represent real system with very precise because it is below 5%.

3.5. Policy Recommendations

3.5.1 Increasing the participation of suppliers.

The low participation of the suppliers, both enterprises and society, can occur for several reasons. To increase the participation of suppliers some policies that we suggest are:

a. Improving socialization and publication of the conversion program of waste cooking oil into Biodiesel to the entire community and relevant stakeholders.

The lack of information and understanding of the program performed by the government of Bogor. So that the socialization of the background, benefits, objectives and technical matters of these activities become very important to be conducted, especially for the stakeholders involved throughout the supply chain.

b. Forming a team of waste cooking oil collectors.

Based on the on interviews with BPLH Bogor, currently collecting waste cooking oil from all suppliers is only done once a week using a mobile unit. Waste cooking oil potential is so big that can not be absorbed optimally with collection systems that exist today. A large number of suppliers that spread around the city was the main reason the collection of waste cooking oil can not be fully utilized

c. Reward and punishment system

If socialization to stakeholders has been done earlier then the sustainability of the program must be be maintained by a system of reward and punishment by the goverment as the organizer of the program. Reward and punishment is a feedback the stakeholders obtained depending on how their performance along the supply chain in carrying out their respective roles. Reward is an appreciation given to certain parties to obtain the optimum working results and cause a feeling of acceptance and engaged in the work environment. Reward touches aspects of compensation and other aspects of the relationship between the relevant parties. Reward can be in the form of materials as well as award or charter [14]. Punishment is a feedback given to those who violate the rules or agreements so as to improve its performance in the future. Punishment can act as a behavior barrier, motivator, and giver of deterrent effect [15].

d. Build a waste cooking oil collection centers.

Good infrastructure is one of the important points in operating a supply chain. Waste cooking oil collection activities closely related to the storage location of the waste cooking oil before being processed into biodiesel. Currently, the waste cooking oil is stored in BPLH office with low capacity and poor inventory management. BPLH office location as well as less strategic if it is seen from the distance with the plant (PT. BEE) and suppliers that spread around the city. In supply chain management there are several strategic steps that can be applied to optimize supply chain performance. One of them is strategic network optimization, including the number, location, and size of warehouses and distribution centers [16].

e. Converts angkot into Transpakuan as the main mode of public transport.

The inefficient transportation in Bogor can be seen from many points prone to congestion. Irregular traffic, the amount of shadow terminal, the provision of transport services which overlap, and yet the realization of intermodal integration into some of the things that must be considered [17]. Angkot is one of the main causes of these problems. So we need an alternative solution that can address the above problems. Transpakuan emerged as one of the solutions offered by the government of Bogor. As consumers of waste cooking oil-based biodiesel, Transpakuan is a major stakeholder that causes biodiesel product demand is always there every year.

f. Support the development of the biodiesel industry.

The realization of 100% absorption of waste cooking oil potential to be processed in to biodiesel requires the commitment of all stakeholders along the supply chain. Especially the government of Bogor and BPLH as the program organizer. Optimizing the supply of waste cooking oil must be balanced with the development of the biodiesel industry as a manufacturer.

4. Conclusion

Supply chain systems that exist today can not guarantee the sustainability of the supply of waste cooking oil as a raw material for biodiesel up to 10 years into the future. Coupled with the plan of using a mixture of biodiesel and diesel fuel with a higher yield and increase the number Transpakuan. Both of these will increase the demand for biodiesel annually. Several scenarios are assumed to occur during the next 10 years include: (1) a scenario without changes or bussiness as usual, that the level of participation of suppliers by 0.4%. The rate of mandatory yield, rate of increase in production capacity, as well as the rate of increase in the number of Transpakuan respectively is 0; (2) The scenario of increasing participation of suppliers to 10% per year and the growth rate of mandatory yield is 12.5% per year; and (3) a scenario of increasing suppliers participation to 50% per year, the growth rate of Transpakuan as much as 10% per year, and the growth rate of production capacity is 10% per year.

There are targets of adding **Transpakuan bus corridors and peraturan menteri ESDM No. 12 Tahun 2015** tentang Energi Baru Terbarukan within the next 10 years to create higher demand for biodiesel in Bogor [18]. To meet the needs of the biodiesel, it requires continuous supply chain of waste cooking oil as a raw material of biodiesel. This can be achieved by increasing the participation of suppliers. In general, the policies proposed to overcome the problem are consists of doing socialization of converting waste cooking oil into biodiesel for all stakeholders involved throughout the supply chain, forming a waste cooking oil collector team to each district in Bogor, implementing a system of reward and punishment for stakeholders in the entire supply chain based on the performance of each in meeting targets, supporting the development of the biodiesel industry, and build an infrastructure that supports the sustainability of the supply of waste cooking oil effectively and efficiently.

Recommendation

The model can be developed wider by adding several sub models, such as the price of diesel, biodiesel prices, the financial analysis of the project, and the environmental aspects that affect along the supply chain. With more data and more complex models, the simulation results will be more accurate when compared to real system.

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