A facility location problem for palm-oil-based biodiesel plant: case study in North Sumatera Province

Fitriani Tupa R. Silalahi, Togar M. Simatupang and Manahan P. Siallagan
1Bandung Institute of Technology, School of Business and Management, Jl. Ganesha No 10, Bandung 40132, Indonesia
2DeI Institute of Technology, Faculty of Engineering Management, Laguboti, Sumatera Utara 22381, Indonesia
*Email: fitriani_tupa@sbm-itb.ac.id

Abstract. As a country that supports the development of renewable energy, Indonesia has policies to direct the use of biodiesel as fuel energy source. In 2020, the Government of Indonesia (GoI) implements mandate of biodiesel from palm oil, one of Indonesia's best plantation products. The increase in the mandate up to B30 makes the national biodiesel plant's capacity to operate up to 80% so that a new plant is needed to meet biodiesel for national and export demand. Taking North Sumatra province as the location of study, this research expects to determine the biodiesel plant's location that will be built to meet the needs of petrodiesel fuel in the North Sumatra area to minimize transportation costs at each stage. Mathematical modelling is conducted to reach the objective. The model aims to determine the most appropriate location and size of the biodiesel plant to be made, by taking into account the distance between several two-transportation points, the availability of feedstocks, demand, and supply chain costs. Mixed-integer linear programming (MILP) is employed to simulate the model. Result suggests that two regions are suitable locations for establishing biodiesel factories to meet the needs of the people of North Sumatra, namely Langkat Regency and Serdang Bedagai Regency. The result can serve as recommendations for policymakers to minimize the biodiesel supply chain cost in North Sumatra.

1. Introduction
The use of fossil energy is an issue that is concerned in many countries because of the depleting fossil energy reserves and its impact on environmental emissions. Biofuels is one of the types of renewable energy being developed to address that concern. Indonesia is also trying to increase biofuels usage through the mandate of biofuel blends [1]. Specifically, for biodiesel, through the Minister of Energy and Mineral Resources Regulation No. 12 of 2015 related to mixing diesel fuel with biodiesel, the Indonesian government seeks to increase biodiesel consumption with palm oil as raw material, which is one of the mainstay products of Indonesian plantations. Indonesia is the country with the largest palm oil producer in the world. As a perennial crop with a permanent leaf canopy, oil palm can grow all year round, which is one of the main reasons why its productivity is so high compared to other vegetable oil crops [2]. With sufficient raw materials from within the country, the government's mandate to use biodiesel will be easier to achieve. In addition to meeting energy needs through
renewable energy, biodiesel has also improved the welfare of oil palm farmers [3]. Apart from fuel oil, biodiesel also has great potential in the electric power sector [4].

North Sumatra is one of the provinces with the potential for oil palm plantations and constitutes 14% of Indonesia’s total oil palm [5]. With the increase in the government’s mandate from B20 to B30 in 2020 [1], it impacts the need for an increase in biodiesel industries that will process palm oil into biodiesel. As of 2019, the biodiesel industry’s total capacity in Indonesia is 11.3 million kiloliters [6], with capacity utilization reaching 70% for the B20 mandate. If GoI wants to reach B30, then the biodiesel needed is 9 million liters or about 80% of the existing capacity, assuming there is no increase in demand. Operating capacity is around 85-90% of installed capacity due to machines in service and others [7]. This causes the industry to be unable to export biodiesel as is usually done, so it is necessary to develop the new biodiesel industry plant to meet domestic and export needs. In North Sumatra, there are already four biodiesel plants with a capacity of 1,728,000 KL, all of which are located in Medan City [8]. However, that plant has been allocated to meet national needs because of its location close to the port. In North Sumatra, another biodiesel plant needs to be built to meet the national biodiesel needs because the amount of raw material available in North Sumatra is quite sufficient, which is around 6 million tons per year [5]. One thing that needs to be considered in constructing a biodiesel plant is a suitable location between raw materials and demand. For this reason, a recommendation for a biodiesel plant location is needed to meet the needs of the North Sumatra province.

In order to save biodiesel supply chain costs, this research will determine the location of the biodiesel plant, so the transportation cost minimum. The issues to be discussed include determining the biodiesel plant's location to minimize the biodiesel supply chain cost in the North Sumatra region following the government's mandate. This location determination is expected to produce policy recommendations in the context of saving biodiesel supply chain costs. To the best of our knowledge, there is a lack of emphasis on biodiesel optimization in Indonesia’s case study. Optimization of the biodiesel industry capacity, location of fuel oil terminals and transportation routes will be carried out. Mixed-integer linear programming (MILP) will be developed to simulate this objective.

2. Methodology

This section will describe the mathematical model that was built. The distribution process is as follows. First, palm oil will be processed into CPO in the feedstock area and then sent to the biodiesel factory to be processed into B100 (FAME). Furthermore, following the government's mandate, the B100 is sent to Pertamina's fuel oil terminal to be mixed with diesel (B0) to become B30. After being mixed, B30 is then distributed to the several areas for consumption by the resident.

2.1 System description

Oil palm plantations in North Sumatra are divided into 22 regencies. In this model, it is assumed that fresh fruit bunches are harvested in each area and then sent to the local palm oil mill industry to be processed into CPO for further processing at the biodiesel plant to produce B100 (FAME). The index to be used in this model is shown in Table 1. Before biodiesel is distributed, B100 (FAME) must be mixed with pure diesel (B0) to produce B30. The mixing is carried out at Pertamina's TBBM (Pertamina fuel oil terminal). Currently, 5 Pertamina TBBMs are operating in North Sumatra, namely TBBM Medan, TBBM Sibolga, TBBM Pematangsiantar, TBBM Kisaran, and TBBM Gunung Sitoli [9].
Table 1. Subscript indices used in model development

| Sets | Descriptions | Total | Description |
|------|--------------|-------|-------------|
| \( i \) | biomass location index | 22 | The number of biomass location is based on oil palm potential calculation in each region in North Sumatera. |
| \( j \) | biodiesel plant location (B100) index | 33 | The number of potential biodiesel plant is based on the number of regency in North Sumatera. |
| \( k \) | TBBM location index (blending location index) | 5 | The number of Pertamina’s TBBM in North Sumatera. |
| \( q \) | Demand location index | 33 | The number of demand location is based on the number of regency in North Sumatera. |

Table 2. Parameters and input

| Symbol | Description | Unit | Sources |
|--------|-------------|------|---------|
| \( b_i \) | The potential amount of palm oil in each region | Ton | [5] |
| \( \text{blending\_cap}_k \) | Blending plant capacity | Kiloliter/year | Calculation from [9] & [10] |
| \( \rho \) | Coefficient of conversion of CPO to biodiesel | 0.95 | [11] |
| \( \text{demand\_q} \) | Number of demands in location q | Kl/year | [12] |
| \( \text{transp\_cpo} \) | CPO transportation costs with \( \text{transp}_{\text{cpo}_i} \) means cost by truck and \( \text{transp}_{\text{cpo}_j} \) means cost by ship | USD/ton-CPO | [11] |
| \( \text{transp\_B100} \) | B100 Transportation costs with \( \text{transp}_{B100} \) means cost by truck and \( \text{transp}_{B100s} \) means cost by ship | USD/kl-B100 | [11] |
| \( \text{transp\_B30} \) | B30 Transportation costs with \( \text{transp}_{B30} \) means cost by truck, and \( \text{transp}_{B30s} \) means cost by ship | USD/kl-BX | [11] |
| \( D_{ij} \) | Distance from the location of biomass i to plant B100 j with \( D_{ij} \) means sea distance and \( D_{ijkl} \) means the land distance | kms | Distance calculation from Google Map |
| \( D_{jk} \) | Distance from factory b100 j to blending k with \( D_{jk} \) means sea distance and \( D_{kj} \) means land distance | kms | |
| \( D_{kq} \) | Distance from blending point k to demand point q with \( D_{kq} \) means sea distance and \( D_{kql} \) means land distance | kms | |
| \( \text{cost\_tbbm}_k \) | Operational costs of TBBM in the blending terminal k | USD/year | [13] |
| \( \text{cost\_plant}_j \) | The maintenance and annualized costs of the B100 plant are directly related to its capacity | USD/year | [11] |
2.2 Demand clusters
In this section, demand will be calculated based on the population per region [14]. The division of the territory is carried out based on the division of districts in Indonesia. Therefore, demand is estimated based on the population's percentage to the total annual demand for diesel in Indonesia.

2.3 Production and transportation cost
The means of transportation used in this study are tank trucks and ships. Tank trucks are used to transport CPO from palm oil mills to biodiesel plants, from biodiesel plants to fuel oil terminals, and from fuel oil terminals to demand locations. Ships are used to transport oil in areas that do not have land access. The cost of transportation using an oil truck to transport CPO from PKS to the biodiesel plant, from the biodiesel plant to the mixing point, to the location of demand is 0.14 USD / t-CPO / km ([15], [11]).

The cost of biodiesel production in this study follows the cost of biodiesel production using conventional methods calculated by Fumi et al., which is USD 9.34 million per 28,409 KL of biodiesel produced [11]. To determine the operational costs of biodiesel plants and fuel oil terminal, we carry out calculations by considering the plant capacity using the scaling effect with $SF = 0.7$.

\[ \frac{Cost_a}{Cost_b} = \left( \frac{Size_a}{Size_b} \right)^{SF} \] (1)

Using the scaling effect in Eq 1, it is possible to calculate costs for the different processing steps of biofuel production plants of different sizes.

2.4 Cost Matrix distance description
Transportation is an essential consideration in fuel oil distribution because of the costs involved. Transport and distance between two points determine factors in the number, capacity, and biodiesel plants’ location. The distance between two points in this study is determined by looking at real data through the Google Map. Further, for data between regions that require sea transportation, the distance between ports is calculated using the Netpas Software.

2.5 Mathematical modeling
The model built aims to determine the most appropriate location and size of the biodiesel plant to be made, taking into account the availability of feedstocks, demand, and supply chain costs. This model also accommodates the scenario if there is additional demand or changes in the biodiesel plant. The model will not optimize at the minimum cost in one sector but minimize biofuel's overall cost for the region welfare.

The total cost of the system and the descriptions is shown in Eq. (5)-(11). Cost 1 is the cost incurred for the transportation of raw materials from raw material sources to the biodiesel industry location. Cost2 is the cost spent to bring B100 to the fuel oil terminal's location to be mixed with petrodiesel to become B30. Cost 3 is the transportation cost to transport B30 from the point of delivery and then sent to all demand locations. Cost 4 is the plant setup cost/capital cost if the fuel oil terminal is opened. Cost 5 is the cost of the plant setup cost if the factory is opened.

\[ f(x,y,t,z,v,w) = \min(cost_1 + cost_2 + cost_3 + cost_4 + cost_5) \] (5)

\[ cost_1 = \sum_i \sum_j D_{ijs} \timesTranspose_{cp} \times x_{ij} + D_{iji} \timesTranspose_{cpol} \times x_{ij} \] (6)

\[ cost_2 = \sum_j \sum_k (D_{jkl} \timesTranspose_{B100} \times y_{jk} + D_{jkl} \timesTranspose_{B100} \times y_{jk}) \] (7)
\[
\text{cost}_3 = \sum_k \sum_q (D_{kq} \cdot \text{trans}_{B30} \cdot z_{kq} + D_{kql} \cdot \text{trans}_{B30l} \cdot z_{kq})
\]

\[
\text{cost}_4 = \sum_k w_k \cdot \text{cost}_{tbbm_k}
\]

The main constraint functions are as follows: The amount of biomass sent to the biodiesel plant does not exceed the total amount of biomass available in the area, the amount of biomass sent to the biodiesel plant \(j\) does not exceed the maximum capacity of raw materials that can be processed by the plant, the amount of B100 sent from factory \(j\) to blending \(k\) to be blended does not exceed the maximum blending capacity for mixing 30\% B100 and 70\% petrodiesel, biodiesel and petrodiesel used is the same as the amount of demand according to the government mandate.

3. Results and discussions

To determine the optimal location, the model that has been described is solved using optimization software CPLEX IDE 12.10.0 with an Intel Core i7 2.9 GHz computer, 8GB RAM, and a 64-bit system. The model that is built produces an optimal solution with the number of variables 1094 and constraint 1291.

The analysis found that to meet biodiesel's needs in North Sumatra, the most suitable biodiesel plant locations are Langkat regency and Serdang Bedagai regency with their respective capacities feedstock locations and TBBM points as shown in table 3. These results are obtained by considering the location of feedstock's, the Pertamina TBBM site, and the demand location. For the Langkat area, the biodiesel plant to be built has a capacity of 385,386 with raw materials coming from the Langkat area itself. After the B100 is produced in Langkat, it is sent to TBBM Medan and TBBM Kisaran to be mixed with petrodiesel to produce B30. For the Serdang Bedagai area, the biodiesel plant to be built has a capacity of 163,996 with raw materials coming from Serdang Bedagai regency and Labuhan Batu Selatan regency. After the B100 is produced in Serdang Bedagai, it is sent to TBBM Sibolga, TBBM Gunung Sitoli, and TBBM Pematangsiantar to be mixed with petrodiesel to produce B30.

| No | Selected biodiesel plant locations | Capacity | Feedstock Locations | TBBM points |
|----|------------------------------------|----------|---------------------|-------------|
| 1  | Langkat                            | 385,386  | Kab. Langkat        | TBBM Medan & TBBM Kisaran |
| 2  | Kab. Serdang Bedagai & Kab. Labuhan Batu selatan | 163,996 | TBBM Sibolga, Gunung Sitoli, TBBM Pematangsiantar |

Next, the location of demand served by each Pertamina's fuel oil terminal is presented in Table 4. This table shows the demand areas that must be served by each TBBM.

| No | TBBM          | Distribution Locations                               |
|----|---------------|-------------------------------------------------------|
| 1  | Medan         | Simalungun, Dairi, Karo, Deli Serdang, Langkat, Pak-Pak Barat, Samosir, Serdang Bedagai, Batubara, Tebing Tinggi, Medan, Binjai |
| 2  | Sibolga       | Mandailing Natal, Tapanuli Selatan, Tapanuli Tengah, Tapanuli Utara, Toba Samosir, Labuhan Batu, Humbang Hasundutan, Samosir, Padang Lawas Utara, Padang Lawas, Labuhan Batu Selatan, Sibolga, Padang Sidempuan |
| 3  | Gunung Sitoli | Nias, Nias Selatan, Nias Utara, Nias Barat, Gunung Sitoli |
| 4  | Pematangsiantar | Simalungun, Pematang Siantar |
| 5  | Kisaran       | Labuhan Batu, Asahan, Labuhan Batu Utara, Tanjung Balai |
Validation of the model is done by looking at the sensitivity analysis of the resulting model. The results of the sensitivity analysis are shown in Figure 1. The sensitivity of the parameters that will affect the final cost is analyzed. The parameters considered are land transportation cost, sea transportation cost, TBBM capacity, and demand. The effect of each parameter was investigated with a change of +30% and -30%. Sea transportation costs have little impact on final costs, which are below 3%, but land transportation costs significantly change, up to 20%. Differences in TBBM capacity affect final cost but are not significant, meaning that the current TBBM capacity has been optimal. The most influential parameter is demand. The changing parameter of the amount of raw material does not affect at all, meaning that the amount of raw material is sufficient to meet demand needs.

4. Conclusions

The government supports the use of biofuels in Indonesia by mandating the use of biodiesel. By 2020 the mandate requires a mix of 30% biodiesel with petrodiesel (B30). For B30, the need to biodiesel is 9 million liters or about 80% of the existing national capacity. Thus, there is a need for a new biodiesel plant to be built to meet the demand for national and exports, given that the palm oil raw material is still sufficient to meet these needs. The study takes the biodiesel plant's location in North Sumatra to meet the demand in North Sumatra itself so that the distribution costs are minimum. The distribution costs include biodiesel plant cost, shipping costs from the feedstock site to the biodiesel plant site, the biodiesel plant site to the TBBM Pertamina site, and then from the TBBM Pertamina site to be distributed to the area where it is needed.

From the study results, the optimum location was chosen in 2 areas among 33 districts in North Sumatra, namely Langkat and Serdang Bedagai. The total transportation cost for this calculation is USD 22.44 per KL B30. This cost does not include biodiesel production cost, petrodiesel production cost, and petrodiesel transportation costs from the refinery to each TBBM. The resulting minimum cost from the model is not for minimizing costs in the industrial sector but for the overall minimum cost for regional welfare. The results could be expected to be policy recommendations in determining a biodiesel plant location in North Sumatera province.

Acknowledgement

This study was partly financed by a research grant from the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia.
References

1. MEMR. 2012. Regulation of the Minister of Energy and Mineral Resources Indonesia About Certain Sector Industry Mandatory to Use Biodiesel and Bioethanol as a Fuel Mixture With Certain Mixtures from 2015 to 2025.
2. L S Woittiez, et al. 2017. Yield gaps in oil palm: A quantitative review of contributing factors. European Journal of Agronomy. 83: p. 57-77.
3. F T R Silalahi, T.M. Simatupang, and M.P. Siallagan, Biodiesel produced from palm oil in Indonesia: Current status and opportunities. AIMS Energy, 2019. 8(1): p. 81-101.
4. N Indrawan, et al., Palm biodiesel prospect in the Indonesian power sector. Environmental Technology & Innovation, 2017. 7: p. 110-127.
5. MoA, Tree Crop Estate Statistics of Indonesia 2018 - 2020: Palm Oil. 2020, Directorate General of Estates Ministry of Agriculture: Jakarta.
6. USDA, Indonesia Biofuels Report 2019, 2019: Jakarta.
7. I F Timorria. Industri Biodiesel Butuh Investasi untuk Tambah Kapasitas. 2019 [cited 2020 September 04].
8. Aprobi. 2020. Anggota Aprobi.
9. MIGAS, B., Laporan Kinerja BPH Migas Tahun 2016 (BPH Migas Performance Report Year 2016). 2016, BPH MIGAS: Jakarta.
10. MIGAS, B. Laporan Kinerja BPH Migas Tahun 2019. 2020
11. F Harahap, S Silveira, and D. Khatiwada. 2019. Cost competitiveness of palm oil biodiesel production in Indonesia. Energy, 170: p. 62-72.
12. Statistik, B.P., 2010. Hasil olah cepat penduduk Indonesia menurut provinsi, kabupaten/kota, dan kecamatan sensus penduduk 2010. Badan Pusat Statistik (BPS).
13. R Nossar, 2020. Kapasitas terminal BBM Tuban ditambah (Tuban BBM terminal capacity is increased). Kontan.
14. H Jeong, H L Sieverding, and J J Stone, 2018. Biodiesel Supply Chain Optimization Modeled with Geographical Information System (GIS) and Mixed-Integer Linear Programming (MILP) for the Northern Great Plains Region. Bioenergy Research.
15. N Mahmudahl.2012. Study of Regional Transportation for CPO in Central Kalimantan. in Proceedings of the 15th International Symposium FSTPT. 2012.