Optimal Design for Biodiesel Supply Chain: Case Study

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Abstract

One renewable energy form currently being promoted is that of biodiesel as a substitute for diesel fuel. This involves mixing biodiesel with petrodiesel in proportions governed by the respective regulations of each country. The purposes of this research are to support the exploiting of biodiesel forms of renewable energy and to optimize the palm oil-sourced biodiesel supply chain by conducting an Indonesia-based case study. The optimization process was implemented in accordance with the government's mandate and long-term planning. There are two decision variables to consider. First, the model will identify the optimum delivery point locations as a blending terminal between biodiesel and petrodiesel (petroleum diesel). Second, it will determine the location of biodiesel plants' construction in order to satisfy the government's mandate. The results show that, while determining delivery point locations affects supply chain costs, it does not do so significantly. More influential is determining the construction locations of biodiesel plants and this study provides a model for deciding the delivery points and locations of biodiesel plants in order to minimize biodiesel supply chain costs in Indonesia. This

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study presents in detail biodiesel supply chain process in Indonesia and based on the literature, no research was found on studying optimization biodiesel supply chain in Indonesia.

Keywords: Biodiesel, palm oil, optimization, supply chain, Indonesia, delivery point, facility location.

1 Introduction

Human dependence on fossil energy, especially within the transportation sector, has become an increasing concern during the present decade. Human beings remain highly dependent on non-renewable energy sources, with 79.9% of energy used being derived from fossils [1]. In addition to depleting fossil fuel reserves, the burning of non-renewable fossil fuels also causes significant climate change-related problems due to the resulting greenhouse gas emissions [2]. Various uses of alternative renewable energy have been developed to reduce dependence on fossil fuels. Consequently, substituting biodiesel for fossil fuels such as petrodiesel (fuel derived from petroleum) is increasingly being undertaken by numerous countries as a means of reducing dependence on fossil energy. Replacing fossil fuels with other forms is not only intended to reduce negative climatic impact, but also to reduce oil dependency and thus improve energy supply security [3]. One of the countries supporting the development of biodiesel is Indonesia.

To simplify the content of this article, the initials BX should be taken to signify the blending of x percent biodiesel with $100 - x$ percent petrodiesel. The use of biodiesel/petrodiesel blends as alternative fuels has been tested in various countries as part of their governments' mandate to reduce the exploitation of rapidly depleting fossil energy reserves. Countries that already have mandatory biodiesel use policies as quoted in [4] include; Colombia with a B10 target based on raw materials derived from palm oil, Ecuador with a B10 target, Paraguay with a B2 target by 2018, Australia with a B0.5 target, Malaysia with a B10 target in the transportation sector and B7 in the industrial sector, Philippines with a B2 target, Thailand with a target approaching B20 and Indonesia, as the first country to mix biodiesel, with a target of B30 by 2020 [5].

In order to be able to apply BX rules, a country requires the necessary resources, technology, distribution facilities and transportation in order to be able to reach consumers. This analysis of preparedness relates to the entire production supply chain, from the availability of land, through distribution, to the delivery of fuel to the consumer. Various aspects of the supply chain, such as network configuration, design, and operation under uncertain conditions, planning decisions, and entire supply chain management, have been analyzed by several authors. Andersen et al. (2012) completed an optimal design and plan for the Argentinian biodiesel supply chain, while taking land competition and alternative raw materials into account. Furthermore, Santibanez et al. (2014) produced design optimization models to plan sustainable biorefinery supply chains that take numerous pertinent issues into account. Rincón et al. (2015) carried out an optimization of the supply chain of biodiesel produced from palm oil and identified suitable locations for expansion. Other studies [6, 8–12] collectively determine the optimal design of the biodiesel supply chain by calculating the quantity, location, technology, and capacity of biodiesel plants. By considering the location of raw materials and potential transportation challenges, an extensive network can be developed. The biofuel supply chain design influences the overall structure of biofuel production networks, the amount of prerequisite capital investment, the choice of appropriate production technologies and the geographic locations of refineries [13].

Through Ministry of Energy and Mineral Resources Regulation No. 12 (2015) [5] governing the mixing of diesel fuel with biodiesel, Indonesia is endeavoring to increase the consumption of palm oil-derived biodiesel which, as the largest global palm oil producer, it can supply. As perennials with a permanent leaf canopy, palm trees can proliferate their branches throughout the year, which accounts for their much higher productivity compared to that of other vegetable oil crops [14]. In 2018, the country's palm oil production, subsequently used in the manufacture of food and fuel or exported in its original form, reached 45 million tons [15]. Therefore, its potential to utilize biodiesel as a petrodiesel mixture fuel is considerable. The use of palm oil has also been proven to have improved Indonesian producers' standard of living as summarized in [16]. In the economic field, the use of biodiesel as a component of diesel fuel has reduced oil imports, thereby maintaining national foreign exchange reserves. Since the regulations regarding the use of B20 across all sectors were implemented in September 2018, domestic consumption of biodiesel up to the third quarter of 2019 resulted in foreign exchange savings of approximately US$2.37 billion [17]. In addition, processing palm oil into fuel will increase the demand for it, improving, in turn, the welfare of farmers. Furthermore, the oil is produced in-country and transactions will, consequently, be conducted in Rupiah, the national currency, both facts which are economically beneficial to Indonesia.

The biodiesel policy was initiated in Indonesia in 2009 and involved the establishing of its B20 target up to 2018. The government has promoted the consumption of B20 fuel across all sectors in the hope of increasing it to B30 by 2020. However, this policy has experienced constraints in relation to the distribution structure due to Indonesia being an archipelago. The distribution of raw materials and fuel oil ready for mixing incurs huge costs since it involves both land and sea transportation. The country consists of 17,504 islands which, in 2019, were divided into 514 regencies [18]. This renders the distribution pattern of fuel oil in Indonesia the most complicated in the world [19] and there is a consequent pressing need to study the entire biodiesel supply chain (from raw materials to consumers) in order to minimize costs and maximize profits through the implementation of BX policies.

In Indonesia, Pertamina, the state-owned oil and gas mining company, constitutes the entity managing production of the majority of fuel oil and mixes B100 biodiesel with fossil fuels. In distributing 20% fuel oil mixed with biodiesel (B20 distribution), Pertamina supplies 112 TBBM (Fuel Oil Terminals) before the fuel oil is distributed to refueling stations (SPBU). Before being distributed to a fuel oil terminal, Pertamina will determine which delivery point from among those available TBBM will act as the mixing point for B0 and B100. In 2018, all fuel oil terminals were designated as delivery points with the result that the mixing of B0 and B100 is conducted in all of these facilities. However, this approach is considered inappropriate due to the resulting hefty increase in operational costs [20]. Consequently, Pertamina changed its approach to determining delivery points by selecting ten fuel oil terminals which produce a mixture of B0 and B100 before dispatching it to other fuel oil terminals. Interestingly, the face-to-face interviews conducted by one bioenergy expert in Indonesia led him to the conclusion that each of the country's provinces must house a delivery point. For this reason, the first objective of this study is to identify the optimal number of delivery points necessary to meet domestic demand for biodiesel. While future government plans include the adoption of policies additional to B50 [21], current limited industry capacity remains sufficient only to satisfy demand for B30. Therefore, the second objective of this research consists of determining appropriate locations for further biorefinery development. On the other hand, both the petrodiesel and biodiesel industries seek to maximize profit and minimize expenditure with the result that the decision regarding mixing facility locations will affect transportation costs. For this reason, point setting should be undertaken to minimize the costs of the entire supply chain, not simply those relating to one industry.

Issues to be discussed include minimizing biodiesel supply chain costs in accordance with the government mandate. To the best of the authors' knowledge, there is a lack of emphasis on biodiesel supply chain optimization in the case of archipelagic countries such as Indonesia. The optimization of the economic aspects of delivery point capacity and location will be undertaken. Mixed integer linear programming (MILP) will be developed to simulate the location of biodiesel feedstock, biodiesel plants, petrodiesel plants, and delivery points, in addition to the amount of flow through transport routes culminating in minimum supply chain costs.

The remainder of this paper is organized in the following manner. Section 2 contains biodiesel distribution identification. The methodology for the formulation and mathematical functions of the model is discussed in Section 3. Section 4 presents and briefly discusses the result of the study and sensitivity analysis, while conclusions are drawn in Section 5.

2 Biodiesel Distribution Identification

The contemporary biodiesel supply chain in Indonesia is describes as follows. Palm oil in Indonesia is produced in 214 regencies. At present, there are 20 functioning B100 biodiesel plants located close to the sources of their raw materials. With regard to solar (petrodiesel) plants, those relating to B0 or petrodiesel are located at half a dozen points distributed across six different regions. B100 and B0 will subsequently be mixed to produce BX at delivery points which represent part of 112 state-owned fuel oil terminals (managed by Pertamina, the state-owned oil and gas industry company). After being mixed at a delivery point, BX is subsequently distributed to 514 community residential locations.

The biodiesel distribution process in Indonesia comprises several stages. First, Pertamina, acting on behalf of the government, determines the amount of diesel to be produced, issues its biodiesel requirements, establishes the criteria to be met by companies in order to become a biodiesel supplier and, finally, communicates this prerequisite to relevant parties. The government then selects those producers who satisfy the requirements. The biodiesel producer sends B100 to the delivery point, which is chosen from among the 112 Pertamina-owned fuel oil terminals, to be mixed with B0. The diesel refinery also dispatches quantities of B0 to the delivery point. Furthermore, the state oil company combines B100 with B0 there to produce B20 or B30 in accordance with government policy. B30 is subsequently despatched to all TBBMs throughout Indonesia to be distributed among consumers. At

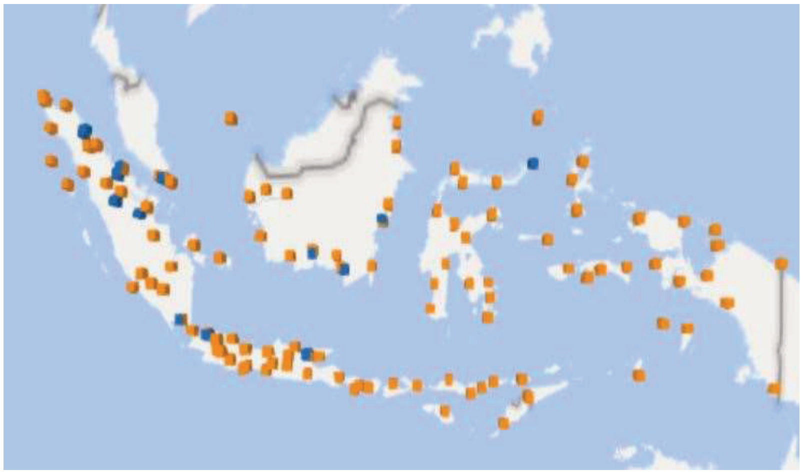

Figure 1 Biodiesel plant locations and Pertamina fuel oil terminal locations in Indonesia (Data derived from [23] and [24]).

present, biodiesel providers with a total capacity of 11,357 million liters are sited in various locations to meet domestic and export demands [22]. Diesel providers operate in six locations, while fuel terminals are to be found in 112 locations in various parts of the country. As an archipelago, Indonesia's geography renders the transportation element of biodiesel supply chains more challenging because it requires the use of both land and sea routes.

Figure 1 provides an overview of the biodiesel infrastructure within Indonesia. The blue dots represent biodiesel plants, while their orange counterparts indicate the location of Pertamina fuel oil terminals. The former are concentrated on two islands, namely; Sumatra and Kalimantan, while the fuel oil terminals facilities are distributed throughout the country to service places of high demand. The presence of a biodiesel facility servicing market demand obviously requires a comprehensive transportation network in order to keep overheads to a minimum. The distribution processes illustrated in Figure 2 comprise the various steps in the dispatch of biomass to each biodiesel plant and from each blending location to its corresponding demand location.

3 Methodology

The purpose of this section is to provide a detailed description of the mathematical model developed and implemented. The mixed integer linear programming (MILP) function was introduced to optimize the flow of palm

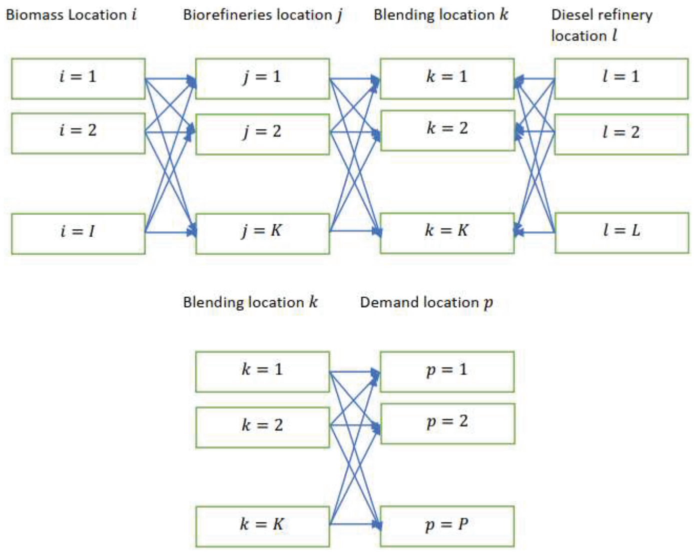

Figure 2 Structure of biodiesel distribution in Indonesia.

oil, B0, B100 and BX in order to minimize BX supply chain costs up to the demand location.

3.1 System Descriptions

Palm oil plants are distributed across 214 regencies in Indonesia. Within this model, it is assumed that fresh fruit bunches (FFB) are harvested in each region and sent to local palm oil mills to be processed into CPO which is then transported by road to 20 biodiesel plants usually located in close proximity to areas of high productivity. At these plants, CPO is converted into B100 biodiesel. The index to be used in this model is displayed in Table 1, decision variables in Table 2, the parameters in Table 3, and a summary of cost factors in Table 4.

3.2 Demand Clusters

The model in this study was developed to achieve the government's target of expanding the biodiesel program to BX. Determination of the level of demand is based on the distribution of the population within each location [11]. Therefore, the total demand in each regency is equal to the number of its inhabitants as a percentage of the total population of Indonesia multiplied

Table 1 Subscript indices used in model development

Sets	Descriptions	Total	Description
i	Biomass location index	214	Total number of points is based on oil palm potential in each continent.
j	Biorefinery (B100 plant) index	20	Total number of biodiesel plants
k	Delivery point index	112	Total number of fuel oil terminals
l	Petrodiesel plant index	6	Total number of petrodiesel units
q	Demand location index	514	Adjusted according to the number of regencies in Indonesia

Table 2 Decision variables employed in model development

Symbol	Unit
x_{ij} = the amount of biomass sent from i to j	tons per year
y_{jk} = the amounts of B100 sent from j to k	kl per year
t_{lk} = the amount of diesel delivered l to k	kl per year
z_{kq} = the amount of biodiesel sent from the blending location k to demand q	kl per year
w_k = the delivery point plant is open or not	binary
v_l = the B100 plant is open or not	binary

by the total solar (diesel) consumption in Indonesia. Total demand for diesel consumption in this study estimate as 32,000,000 kl [25].

3.3 Production and Transportation Costs

The price of palm oil and biodiesel is determined on a monthly basis by government regulations published in the form of a biofuel market index [32]. The price changes according to external factors such as current market conditions and world oil prices. In this paper, minimal production costs are estimated by monitoring the entire supply chain. However, the approximation is arrived at by taking the cost of production and transportation into account without considering changes in palm oil prices.

The total combined cost of road tanker transportation of CPO from palm oil mill to the biodiesel plant, from there to the mixing point, and, finally, to the demand location is USD0.14/t-CPO/km ([33, 27]). Taking into account the specific gravity of biodiesel and petrodiesel, the transportation cost for B100 is USD0.123/kl-biodiesel/km, while that of B0 is USD

Table 3 Parameters and input

Symbol	Description	Unit	Sources
b_i	The potential amount of palm oil in each region	tons/year	[15]
$biomass\_cap_j$	Biodiesel plant capacity	kl/year	Visit to Aprobi
$blending\_cap_k$	Blending plant capacity	kl/year	[23]
$diesel\_cap_l$	Diesel plant capacity	kl/year	[26]
ρ	Coefficient of conversion of CPO to biodiesel	0.95	[27]
$demand\_q$	Number of demands in location q	kl/year	[28]
$transp\_cost\_cpo$	CPO transportation costs	USD/t-CPO	[27]
$transp\_cost\_B100$	B100 Transportation costs	USD/kl-B100	[27]
$transp\_cost\ \_B0$	B0 Transportation costs	USD/kl-B0	[27]
$transp\_cost\_BX$	BX Transportation costs	USD/kl-BX	[27]
D_{ij}	Distance from location of biomass i to plant B100 j	kms	
D_{jk}	Distance from biodiesel plant b100 j to blending k	kms	
D_{lk}	Distance from refinery B0 to blending k	kms	
D_{kq}	Distance from blending point k to demand point q	kms	
$biodiesel\_cost_j$	B100 production costs (including costs for purchasing raw materials) at the biorefinery j	USD/kl	[27]
$diesel\_cost$	B0 Production costs	USD/kl	[29]
$storage\_cost$	Storage costs		
$tbbm\_cost_k$	Operational costs of TBBM in the blending terminal k	USD/year	[30]
$plant\_cost_j$	The maintenance and annualized costs of the B100 plant are directly related to its capacity	USD/year	[27]
$gov\_mandate$	Government mandate		[31]

Table 4 Summary of cost factors

Item	Data	Sources
Transportation costs	0.14 USD/KL/km	[27]
Unit biodiesel production costs with capacity A	Using scaling factor USD9.34 million/28409 kl biodiesel	[27]
Unit biodiesel production costs with capacity B		
Unit diesel production costs	116 USD/kl	[29]
Biodiesel plant costs	USD 141,657,920 for capacity of 350,000 kl	[30]
Biodiesel plant lifetime	25 years	[27]

0.117/kl-petrodiesel/km. For BX in the categories from B20 to B50, the calculated average density underpins an estimated transportation cost for BX of USD 0.119/kl-BX/km.

The calculation of biodiesel production costs in this study follows the conventional methods employed by Harahap et al. [27], giving a total of USD 9.34 million per 28,409 kl of biodiesel produced. To determine the operational costs of each biodiesel, plant a calculation taking its capacity into account by using a scaling effect is undertaken. This scaling effect greatly influences the unit cost per plant capacity which is lower in the case of larger plants or equipment (such as boilers, turbines, etc.) [27]. This difference can be adjusted using the scaling function of each component as shown in Eq 1. SF represents the scaling factor, while $Cost_a$ and $Cost_b$ represent the respective component costs of two different biofuel production plants of $Size_a$ and $Size_b$.

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

The information in Equation (1) can be used to calculate the costs of different processing stages at biodiesel production plants of varying capacities. By adding the investment costs from separate units together, the total investment costs for other sizes can be determined and the production costs for each production plant calculated. Within this analysis, a scaling factor of 0.7 is considered appropriate to adjust capital costs in relation to the size of the equipment, based on data contained in some of the references consulted [27, 34]. This scaling factor is still greater than that for chemical engineering equipment which is equal to 0.6 [35].

In addition to biodiesel production costs, this model also considers the annual maintenance and capital costs. The latter are calculated on the basis of the investment necessary to construct a biodiesel plant (USD141,657,920) with a capacity of 350,000 kl, and assuming a 25-year service life. These capital costs are subsequently adjusted according to the capacity of each plant using the scaling factor. The petrodiesel plant handles more than diesel production and this model is intended to calculate biodiesel supply chain costs. However, due to the unavailability of supporting data, the capital costs for petrodiesel will not be considered.

3.4 Plant and TBBM Capacity

One determining factor in the supply chain to be quantified is the capacity of the biodiesel and delivery point plants. In this study, the biodiesel plant capacity was confirmed by a visit to the Indonesian Biodiesel Producers Association office, while statistical data relating to petrodiesel plant capacity was sourced from the Pertamina website [26]. The calculation of annual TBBM diesel capacity is based on the number of tanks. It is assumed that diesel capacity in TBBM is 15/40 of its total capacity [30] because TBBM not only distributes diesel, but also other types of fuel such as gasoline and gas.

3.5 Transportation Cost Matrix

Transportation is the most important factor when calculating distribution costs by multiplying transportation costs by the distance to be travelled between two points. The method adopted in this study to determine the distance between two points is the longitude and latitude-based Haversine formula.

Calculation of the distance from one point on the earth's surface to another is affected by the degree of curvature. Therefore, the adopted method of calculating such distances greatly influences the accuracy of the results obtained. In this study, the Haversine formula is employed to calculate precisely and accurately the distance between two points by means of latitude and longitude. By knowing the location of each point, the distance between points can be measured. The distance between two points on the surface of the earth determined by longitude and latitude (in radians) is calculated using the Equation (2)–(4):

$$(lon_1, lat_1) = (x_1, y_1);\ (lon_2, lat_2) = (x_2, y_2)$$

$$distance\ (x_1, y_1)\ to(x_2, y_2) = d.R \tag{2}$$

Where

$$d = 2sin^{-1}min\left\{sin\left(\frac{y_1 - y_2}{2}\right)^2 + cos\ y_1\ cos\ y_2\ sin\left(\frac{x_1 - x_2}{2}\right)^2\right\} \tag{3}$$

$$R = 6378.388 - 21.476\ \mathrm{sin}\left(\frac{y_1 + y_2}{2}\right)\mathrm{km} \tag{4}$$

3.6 Mathematical Modelling

The model to be developed is intended to determine the minimum biodiesel supply chain costs from raw material extraction to delivery to the consumer. This model also accommodates scenarios such an increase in demand or changes in biodiesel plant capacity. The total cost of the system developed is contained in Equation (5). $cost_1$ represents the costs incurred in transporting raw materials from their point of extraction to the biodiesel industry site. $cost_2$ constitutes the expenses involved in producing B100 (including the purchase of raw materials) and subsequently transporting it to the delivery point to be mixed. $cost_3$ indicates the cost of producing B0 and transporting it to the delivery point for mixing. $cost_4$ constitutes the expense incurred by transporting BX from the delivery point and then shipping it to all demand locations. $cost_5$ is the plant setup cost/capital cost if the TBBM is employed. $cost_6$ represents the plant setup cost if the plant is subsequently operated.

$$f(x, y, t, z, v, w) = \min(cost\ 1 + cost\ 2 + cost\ 3 + cost\ 4 + cost\ 5 + cost\ 6) \tag{5}$$

where

$$cost\ 1 = \sum_i \sum_j D_{ij} * transp\_cost\_cpo * x_{ij} \tag{6}$$

$$cost\ 2 = \sum_j \sum_k \begin{array}{c}(biodiesel\_cost_j * y_{jk} + D_{jk} * transp\_cost\_B100 * y_{jk} \\ + blend_{cost} * y_{jk})\end{array} \tag{7}$$

$$cost\ 3 = \sum_{l}\sum_{k} (transp\_cost\_B0 * D_{lk} * t_{lk} + t_{lk} * diesel\_cost) \tag{8}$$

$$cost\ 4 = \sum_{k}\sum_{q} (D_{kq} * transp\_cost\_BX * z_{kq} + storage\_cost * z_{kq}) \tag{9}$$

$$cost\ 5 = \sum_{k} w_k * tbbm\_cost_k \tag{10}$$

$$cost\ 6 = \sum_{k} v_j * plant\_cost_j \tag{11}$$

with the following constraint functions:

Constraint 1: The amount of biomass sent to the biodiesel plant does not exceed the total amount of biomass available ($biomass\_cap$) in the area.

$$\forall\, i,\ \sum_{j} x_{ij} \leq biomass\_cap_i \tag{12}$$

Constraint 2: The amount of biomass sent to the biodiesel plant j does not exceed the maximum amount of the raw material that can be processed by the plant ($max\_biodiesel\_cap$).

$$\forall\, j,\ \sum_{i} x_{ij} \leq biodiesel\_cap_j * \rho * max\_biodesel\_cap \tag{13}$$

Constraint 3: The amount of biodiesel (B100) produced at each plant does not exceed its maximum operational capacity. It should be noted that in this study the maximum operational capacity of functioning biodiesel plants amounts to 90% of overall biodiesel plant capacity due to a range of factors including; broken machines, engine maintenance and other operational requirements.

$$\forall\, j,\ \sum_{k} y_{jk} \leq cap_j * max\_biodiesel\_cap \tag{14}$$

Constraint 4: The amount of B100 sent from biodiesel plant j to blending k to be mixed does not exceed the maximum blending capacity ($blending\_cap$) for mixing B100 at $gov\_mandate$.

$$\forall\, j,\ \sum_{i} y_{jk} \leq blending\_cap_k * gov\_mandate \tag{15}$$

Constraint 5: Where cap_l is the total B0 petrodiesel production capacity of plant l, the total B0 shipped does not exceed the available B0 petrodiesel plant capacity

$$\forall\, l,\ \sum_{k} t_{lk} \leq cap_l \tag{16}$$

Constraint 6: The amount of B0 sent from the diesel plant to blending k does not exceed the maximum blending capacity for mixing B0 of 1-*gov_mandate*.

$$\forall\, k,\ \sum_{i} t_{lk} \leq blending\_cap_k * (1 - gov\_mandate) \tag{17}$$

Constraint 7: The amount of BX sent from blending k to demand q does not exceed the blending capacity.

$$\forall\, k,\ \sum_{k} z_{kq} <= blending\_cap_k * w_k \tag{18}$$

Constraint 8: The amount of B20 sent to the demand area must equal the number of requests at that point.

$$\forall\, q,\ \sum_{k} z_{kq} = demand_q \tag{19}$$

Constraints 9–11: The amount of biomass, biodiesel and petrodiesel used matches the level of demand according to the government mandate.

$$\sum_{i}\sum_{j} x_{ij} = \frac{gov\_mandate}{\rho} * \sum_{q} demand_q \tag{20}$$

$$\sum_{j}\sum_{k} y_{jk} = gov\_mandate * \sum_{q} demand_q \tag{21}$$

$$\sum_{l}\sum_{k} t_{lk} = (1 - gov\_mandate) * \sum_{q} demand_q \tag{22}$$

Constraint 12: For BX, the composition of the mixture used in the mixing plant k is X% B100 with (100-x)% B0.

$$\forall\, k,\ \sum_{j} y_{jk} = \frac{gov\_mandate}{1 - gov\_mandate} \sum_{l} t_{lk} \tag{23}$$

Constraint 13: Where cap_k is the total holding capacity for diesel fuel in each TBBM k, the number of B0 and B100 at the blending location does not exceed the available blending capacity.

$$\forall\, k,\ \left(\sum_{j} y_{jk} + \sum_{l} t_{lk}\right) \leq cap_k \tag{24}$$

Constraint 14: The relationship between the biomass (tons) and biodiesel (B100) produced is equal to the conversion efficiency ρ. In biodiesel production, 950 liters of biodiesel is obtained from 1 ton of CPO [36]. Therefore, the value of ρ in the production of biodiesel from palm oil is 0.95.

$$\forall\, j,\ \sum_{j} y_{jk} = \rho \sum_{j} x_{ij} \tag{25}$$

Constraint 15: Relations/number of B20 sent must equal the sum of the number for B0 and the number for B100.

$$\forall\, k,\ \sum_{j} y_{jk} + \sum_{l} t_{lk} = \sum_{q} z_{kq} \tag{26}$$

Constraints 16–19:

$$x_{ij} \geq 0 \tag{27}$$

$$y_{jk} \geq 0 \tag{28}$$

$$t_{lk} \geq 0 \tag{29}$$

$$z_{kq} \geq 0 \tag{30}$$

4 Results and Discussion

As explained above, applying the model presented in this paper involves the use of a case study from Indonesia. The model was implemented using CPLEX IDE 12.10.0 optimization software. Experiments were carried out on an Intel Core i7 2.9 GHz computer with 8 GB of RAM on a 64-bit system. Mixed integer linear programming built on a basic scenario consists of 64,892 variables with 67,768 constraints. The time taken for solutions to be

Table 5 Scenario description

Scenario	Government Mandate	Description	Variable	Constraint
Scenario 1 (S1)	B20	$i = 214;$	64,892	67,768
		$j = 20;$		
Scenario 2 (S2)	B30	$k = 112;$		
		$q = 514;$		
		$l = 6;$		
Scenario 3 (S3)	B20	$i = 214;$	282,374	287,260
		$j = 20;$		
Scenario 4 (S4)	B30	$k = 514;$		
		$q = 514;$		
		$l = 6;$		
Scenario 5 (S5)	B20	$i = 214;$	226,430	230,294
Scenario 6 (S6)	B30	$j = 514;$		
Scenario 7 (S7)	B40	$k = 112;$		
Scenario 8 (S8)	B50	$l = 514;$		
		$q = 6;$		

obtained varied from 20 seconds to 28 minutes. The model will select the path incurring the lowest cost of transporting from palm oil plantations to biodiesel plants, from biodiesel plants to delivery points, from petrodiesel plants to delivery points and, finally, to the consumers dispersed throughout each regency. The solution provided by this mathematical programming model determines the optimal location of the biomass feedstock's and the amount of palm oil delivered from each feedstock locations, the location and capacity of the biodiesel plant, the amount of biodiesel delivered from each biodiesel plant locations, the amount of petrodiesel delivered from each petrodiesel plant locations and the location and capacity of the mixing facility. Therefore, the solution to this problem is divided into four scenarios as shown in Table 5.

The policy scenarios in Scenario 1 to Scenario 4 outlined in this paper follow the government's policy of implementing B20 in 2018 followed by the B30 policy in 2020. These four scenarios divided into two parts. The first part is selecting delivery points from currently available TBBM set (from current 112 TBBM) and their respective capacities. The first part will be simulated in two types of policies, namely; the B20 policy in Scenario 1 and the B30 policy in Scenario 2. The second part will try to identify the optimum delivery point locations by searching for the optimum delivery point locations for the set of 514 regencies throughout Indonesia. For this reason, delivery points will be chosen from 514 possible regencies with B20 policy in Scenario 3 and B30 policy in Scenario 4. The next scenarios (Scenario 4–Scenario 8) build on future government policy to implement B40 and B50 policies which are feasible in terms of raw materials because, as the leading global producer of palm oil, Indonesia possesses the capacity to supply these. However, biodiesel industry capacity in Indonesia is insufficient to produce all these raw materials. Therefore, Scenarios 4–8 were developed to determine the optimum location of the new biodiesel industry.

4.1 Cost Analysis

In this section, a cost analysis will be produced from the optimization results as shown in Figure 3. It appears that the most elevated costs are $cost$ 2 and $cost$ 3 which relate to producing biodiesel and petrodiesel as well as transportation between the production and blending locations. The production costs for 20% biodiesel combined with those of transport to the delivery point almost match those for 80% petrodiesel. The situation also pertains in the case of B30.

The total cost incurred between B20 and B30 in Scenarios 1–4 (see Figure 4) will differ. Costs incurred in B20 are lower than those in B30 because biodiesel-related production costs exceed those of petrodiesel. However, by adjusting the location of the biodiesel industry, the total cost can be reduced quite significantly (see Figure 4). For B20, the total potential savings of re-locating the biodiesel plant (from S1 to S5), in addition to considering

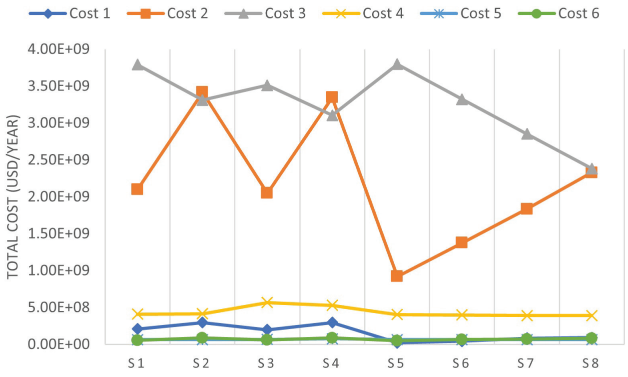

Figure 3 Cost calculation for each scenario.

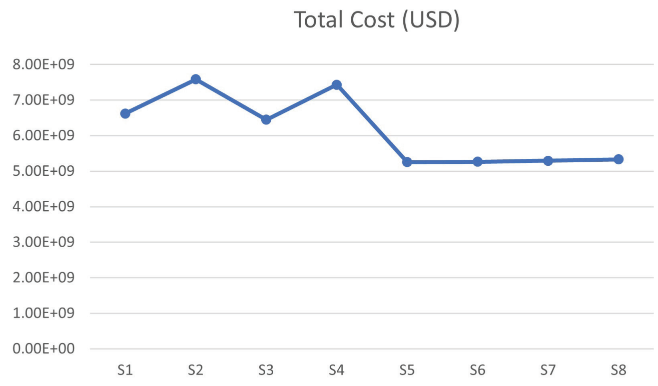

Figure 4 Total cost of each scenario.

the location of the petrodiesel plant, the mixing location, and the demand location, total USD1.37E + 09.

4.2 Optimal Delivery Point

In this section, the optimum delivery points will be discussed. The scenario utilized is restricted to B20 and B30 policies. The government's plan to develop policies up to B50 is not discussed here because of the biodiesel industry's lack of capacity to produce B40 and B50.

Scenarios 1 and 2 relate to the current situation. By using a Hyversine formula distance-based transportation cost calculation, it was established that the optimal mixing point between B0 and B100 is 101 points for B20 and 100 points for B30 (see Figure 5). If, even given the current state of the industry, there is a reorganization of locations and the number of delivery points, the resulting costs will not have a significant effect as seen from Scenario 1 to Scenario 4 in Figure 4. In Scenarios 1 and 2, the delivery points are selected on the basis of the current circumstances and capacity of the TBBM. To develop the results of the study, Scenarios 3 and 4 were investigated by randomly selecting delivery points from among the 514 regencies. Given contemporary TBBM conditions, the capacity of these delivery points is assumed to be an annual maximum of two million kiloliters of diesel. Simulation results show that for B20 as many as 37 delivery points and for B30 up to 46 delivery points were selected. The location of the selected delivery point is a sub-set of the existing TBBM. This means that in each selected delivery point location a TBBM has been constructed. The difference is that the selected delivery point's capacity is greater than the existing TBBM capacity. The savings made for B20 from Scenario 1 to Scenario 3 are USD1.75 + 8, while those for B30 from Scenario 2 to Scenario 4 amount to USD1.45 + 8.

4.3 Optimal Plant Location

In accordance with government policy, additional targets will be set for the development of biodiesel up to B50 [37]. However, the available biodiesel plants currently have insufficient capacity to meet the B40 and B50 targets. For this reason, a recommendation for biodiesel plant location is needed to meet the national needs of incorporating the previous mathematical model. To determine the optimum biodiesel plant locations, the results of Scenarios 5–8 are shown in Table 6 and Figure 5. It is clear that the majority of optimum plant construction sites are centered on Kalimantan. This is due to the presence of adequate resources on the island and its location in the center of the country which renders distribution costs to all corners of the country more economical. The contents of Table 6 indicate that, as far as the most appropriate locations for the construction of plant to achieve B40 and B50 are concerned, these appear to be Central Kalimantan and South Kalimantan.

Determination of the proposed location of the biodiesel plant significantly influences the level of transportation cost reductions. In the case of B20, if the location has been adjusted to current conditions (Scenario 1 compare to Scenario 5), the cost savings amount to 1.37E + 09 (see Figure 5).

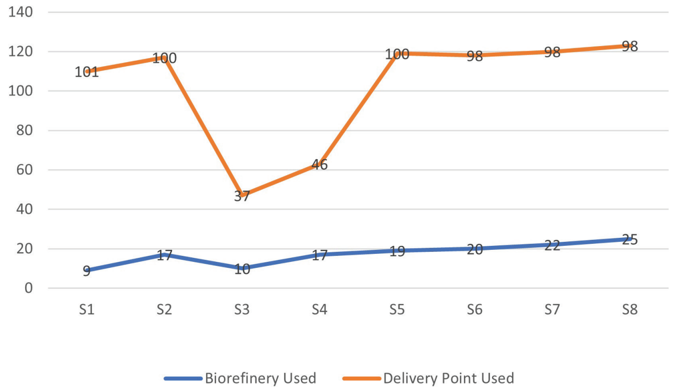

Figure 5 Comparison of total biorefinery used and delivey point used for scenario 1–8.

Table 6 Biodiesel plant capacity in each location

	Biodiesel Plant Capacity				
Province	Current (kl/year)	Scenario 5 (kl/year)	Scenario 6 (kl/year)	Scenario 7 (kl/year)	Scenario 8 (kl/year)
North Sumatra	877,010	297,725	446,588	595,451	591,240
Riau	4,528,735	1,486,042	1,758,829	2,488,085	2,850,494
Bangka Belitung	–	375,334	591,277	786,718	786,718
Lampung	885,058	659,239	698,125	1,158,620	1,163,766
South Sumatra	–	–	292,404	380,910	966,231
West Java	742,756	182,604	210,755	210,755	210,755
Central Kalimantan	402,299	2,137,932	2,307,444	3,427,815	5,185,333
South Kalimantan	440,517	450,880	1,311,415	1,372,344	1,425,061
East Kalimantan	419,540	118,622	124,073	276,177	441,043
West Kalimantan	–	–	846,061	897,940	949,818
Central Sulawesi	–	137,030	192,085	239,504	242,980
West Sulawesi	475,862	241,144	356,769	366,900	348,930
South East Sulawesi	–	197,818	259,212	313,592	331,563
Papua	–	115,631	204,962	285,190	352,995
Kepri	896,552	–	–	–	153,074
East Java	1,952,873	–	–	–	–
Total	**11,621,202**	**6,400,000**	**9,600,000**	**12,800,000**	**16,000,000**

4.4 Sensitivity Analysis

Sensitivity analysis was performed on the most important parameters of the constructed model in order to observe the behavior resulting from any alteration to them. The parameters considered are feedstock share, demand, plant size, production cost and transportation cost. The effect of each parameter is analyzed with changes of $+/-30\%$ (with the exception of demand whose maximum change is only 20% due to insufficient industrial capacity to meet higher levels of demand of up to $+\ 30\%$). The results of the analysis applied to the simulation for Scenario 1 are contained in Figure 6.

The sensitivity of the parameters affecting the final total cost of the biodiesel supply chain costs is based on simulations carried out in Scenario 1. From this analysis, The most important parameters in this study comprise

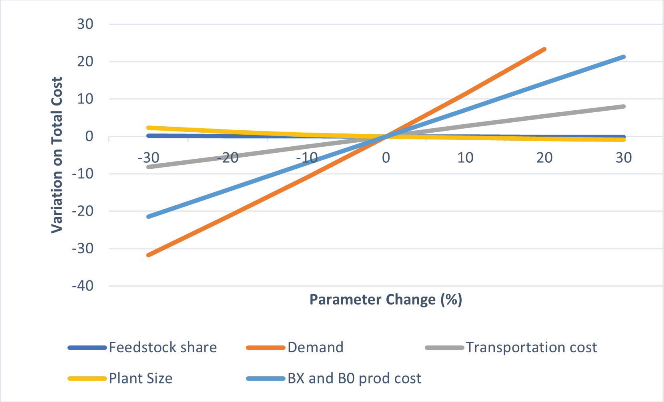

Figure 6 Parameter sensitivity relating to important parameters.

demand, biodiesel production costs and transportation costs. The change of feedstock shares and plant size has a litte influence on total cost: below 3% indicating that the plants optimally located closer to the feedstock and that the amount of raw material is sufficient to meet demand needs. The total cost changes significantly according to fluctuations in demand and production costs.

5 Conclusions

The utilization of palm oil, which represents a mainstay plantation product in Indonesia, in a mixture of petrodiesel fuel strongly supports the development of renewable energy. The government's target of continuing to increase the percentage of biodiesel mix requires synergic support from market players in the domestic petrodiesel fuel industry; the government as policy maker, the petrodiesel industry as the distributor to consumers and the biodiesel industry as the supplier of pure biodiesel.

Two forms of optimization have been carried out in this study. First, the model identifies optimum delivery points by considering the location of four crucial elements, namely; raw materials, the biodiesel industry, the diesel industry, and market demand. Second, the model identifies the optimum site of the biodiesel industry to minimize supply chain costs by considering the locations of raw materials, demand, and delivery points. From the simulation results, it is evident that changes in the selection of the delivery point location do not significantly affect the costs incurred. Of paramount importance is determining the proposed site of the biodiesel industry in order to minimize costs.

The model constructed provides information about the location of the biomass and the amount of palm oil that must be supplied to the biodiesel industry. In addition, information was also obtained regarding the task assigned to the biodiesel industry of sending B00 together with that quantity of palm oil to a specific delivery point. In addition, the delivery point is also tasked with sending BX to each demand location. The sensitivity analysis results show that the parameters exerting greatest influence on costs are those of expenditure on demand and production, followed by transportation. With regard to further research, it is recommended that distance measurements are not based on hypersine formulas but, rather, on actual distances using different means of transportation in accordance with the geographical realities of Indonesia.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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