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Article

Techno-Economic Analysis and Physicochemical Properties of *Ceiba pentandra* as Second-Generation Biodiesel Based on ASTM D6751 and EN 14214

N.A.M. Jamaluddin [1], Teuku Meurah Indra Riayatsyah [2], Arridina Susan Silitonga [3,*], M. Mofijur [4], Abd Halim Shamsuddin [1], Hwai Chyuan Ong [4,5,*], Teuku Meurah Indra Mahlia [4,*] and S.M. Ashrafur Rahman [6]

1 Institute of Sustainable Energy, Universiti Tenaga Nasional, Kajang 43000, Selangor, Malaysia
2 Department of Mechanical Engineering, Syiah Kuala University, Banda Aceh 23111, Indonesia
3 Department of Mechanical Engineering, Politeknik Negeri Medan, 20155 Medan, Indonesia
4 School of Information, Systems and Modelling, Faculty of Engineering and Information Technology, University of Technology Sydney, NSW 2007, Australia
5 Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia
6 Biofuel Engine Research Facility (BERF), Queensland University of Technology, Brisbane QLD 4000, Australia
* Correspondence: ardinsu@yahoo.co.id (A.S.S.); ong1983@yahoo.com (H.C.O.); TMIndra.Mahlia@uts.edu.au (T.M.I.M.)

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Abstract: Processing biodiesel from non-edible sources of feedstock seems to be thriving in recent years. It also has also gathered more attention than in the past, mainly because the biodiesel product is renewable and emits lower pollution compared to fossil fuels. Researchers have started their work on various kinds of biodiesel product, especially from a non-edible feedstock. Non-edible feedstocks such as *Ceiba pentandra* show great potential in the production of biodiesel, especially in the Southeast Asia region because the plants seem to be abundant in that region. *Ceiba pentandra*, also known as the Kapok tree, produces hundreds of pods with a length of 15 cm (5.9 in) and diameter 2–5 cm (1–2 in). The pods consist of seeds and fluff in the surrounding areas inside the pod, which itself contains yellowish fibre, a mixture of cellulose and lignin. The seeds of *Ceiba pentandra* can be used as feedstock for biodiesel production. The study for *Ceiba pentandra* will involve techno-economic, as well as a sensitivity analysis. Moreover, the study also shows that the techno-economic analysis of a biodiesel processing plant for 50 ktons *Ceiba pentandra* with a life span of 20 years is around $701 million with 3.7 years of the payback period. Besides that, this study also shows the differences in operating cost and oil conversion yield, which has the least impact on running cost. By improving the conversion processes continuously and by increasing the operational efficiency, the cost of production will decrease. In addition, the study also explains the differences of final price biodiesel and diesel fossil fuel, both showing dissimilar scenarios subsidy and taxation. Biodiesel has a subsidy of $0.10/L and $0.18/L with a total tax exemption of 15%. The value was obtained from the latest subsidy cost and diesel in Malaysia. Finally, further research is needed in order to fully utilize the use of *Ceiba pentandra* as one of the non-edible sources of biodiesel.

Keywords: techno-economic: life cycle cost; sensitivity analysis; *Ceiba pentandra*; non-edible oil

1. Introduction

Biodiesel is a clean, smouldering, renewable fuel that is usually produced from vegetable oils, animal oil or fats, waste cooking oil and tallow [1–3]. It may be determined by a chemical process

on how the glycerine can be extracted from the vegetable or animal oil [4,5]. The main purpose of biodiesel is to replace the petroleum diesel fuel or to be mixed with petroleum diesel fuel in certain types of uses to reduce greenhouse gas emission [6–9]. Biodiesel is good for the environment because it is comprised of renewable sources that emit fewer emissions compared to petroleum diesel fuel. In Malaysia, they have already started to utilize 10% of biodiesel fuel in the transport sector and 7% in the industrial sector beginning in July 2016 [10]. In biodiesel production, there are many different feedstocks that have been used. Biodiesel can be produced by utilizing edible oils and non-edible oils as resources. In Malaysia and Indonesia, palm oil and coconut oil were commonly used as the edible feedstock in biodiesel production [11–15]. However, usage of the edible oil can result in competition between usages of food against fuel. This also can increase the condemnation of sustainable edible oils for biodiesel production [16–18]. However, many types of non-edible oils can be used as main sources of biodiesel production. This can help to reduce the cost of production, also keeping at bay the conflict of food versus fuel. Besides that, non-edible oils have a reasonable price and are easily obtainable in tropical countries. There are many types of non-edible oils that have been used as feedstock for biodiesel production. For example, from vegetable oils there are *Jatropha curcas*, *Pongamia pinnata* (Karanja), *Madhuca indica* (Mahua), Linseed, Cottonseed, *Azadirachta indica* (Neem), Camelina, *Reutealis Trisperma*, *Calophyllum Inophyllum*, *Hevea Brasiliensis*, *Ricinus Communis*, *Ceiba pentandra*, *Schleichera Oleosa*, *Cerbera manghas* and beauty leaf tree [19–24]. From wasted or recycled oils there are cooking oil, vegetable oil, frying oil, soap stocks and pomace oil [25–33]. Also, there are uses for animal fats such as chicken fat, beef tallow, yellow grease, pork lard and fish oil products [34–41].

Currently, there are plenty of publications discussing algae for biodiesel production. This is due to the potential of the algae in supplying enough oil for global consumption and utilization, as well as global warming caused by burning fossil fuel [42–52]. The usage of algae as non-edible oil has increased throughout the year; this is mainly because of the oil content and making it as the second generation biodiesel production [53]. Besides that, there are other feedstocks such as used vegetable oils, yellow grease, brown grease and soap stock produced from refining vegetable oils [54]. Biodiesel production cost can be reduced due to this type of feedstock being very low in price and easy to obtain. The use of cooking oil as biodiesel for biodiesel production is one of the best options of economical sources [55–59]. Biodiesel production should be focusing on non-edible sources as a way to avoid conflict with food. For that reason, as a non-edible oil, *Ceiba pentandra* can be used as one of the new sources for biodiesel production. Nowadays, the production rate of biodiesel from non-edible feedstock seems to be declining year after year. In order to maintain the production of biodiesel, new sources need to be discovered and a life cycle cost analysis must be conducted. Therefore, this paper will be focusing on *Ceiba pentandra* as the new non-edible biodiesel feedstock. The main objectives of this paper are to assess the *Ceiba pentandra* as a probable source for upcoming energy supply through techno-economic and sensitivity analysis.

2. Materials and Methods

2.1. Materials

Ceiba pentandra is an emergent tree of the tropical rainforests and is often described as majestic, as shown in Figure 1. Locally, it is called Kapok and is the cotton-like fluff that may derive from the seedpods. *Ceiba pentandra* also has many common names such as Kapok tree, *Ceiba de Lana*, silk-cotton tree, etc. *Ceiba pentandra* can be a very large tree with a trunk diameter of up to 3m (9.8 ft.), capable of reaching 70 m (230 ft.). The main trunk and the branches are crowded with thorns around it. The kapok leaves have leaflets of around 5 to 9, and the leaf length is around 20 cm (7.9 in). The Kapok tree produces hundreds of pods with a length of 15 cm (5.9 in) and a diameter of 2–5 cm (1–2 in). The pods consist of seeds and are fluffy in the surrounding areas inside the pod. The pod also contains yellowish fibre, which is a mixture of cellulose and lignin. What makes *Ceiba pentandra* different with other species are the pattern and the sizes of its conical spines [60].

Ceiba pentandra tree

"Kapok" of *Ceiba pentandra*

Ceiba pentandra fruits

Ceiba pentandra leaves

Ceiba pentandra seed within the pods

Ceiba pentandra dried seed

Figure 1. *Ceiba pentandra* at rural area in Malaysia.

Ceiba pentandra can be found all around the world, such as in Indonesia, Malaysia, South and Central America, Mexico, West Africa, and Caribbean islands as shown as Figure 2.

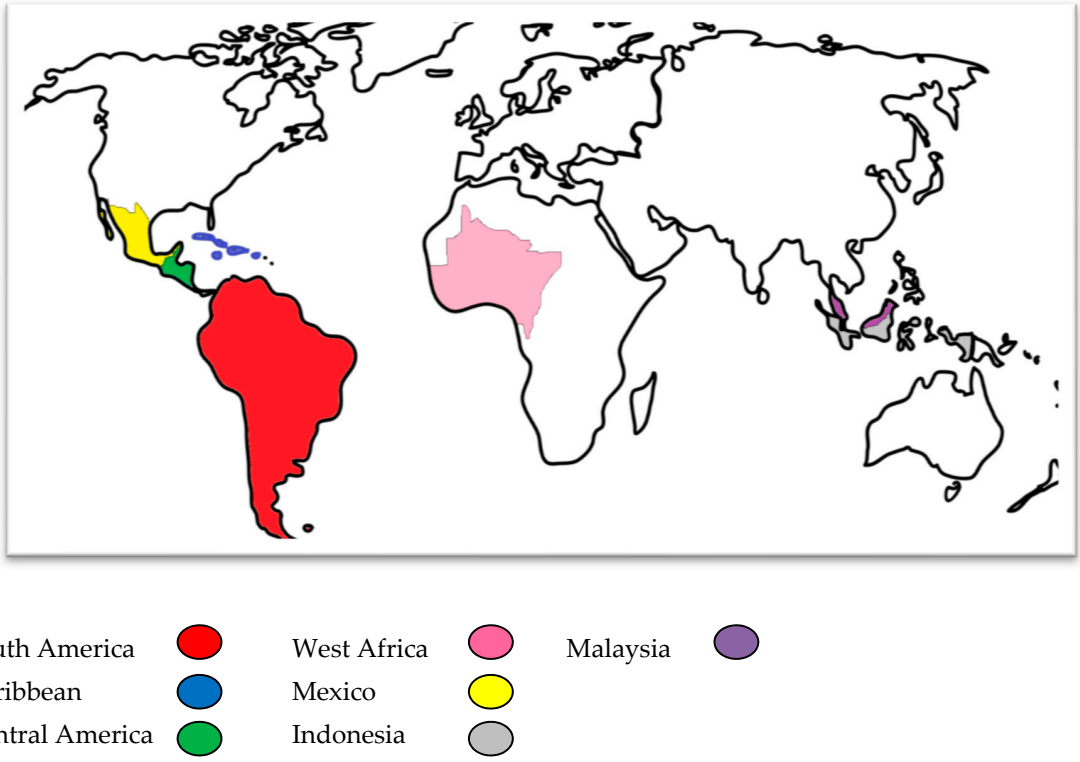

Figure 2. Worldwide location of *Ceiba pentandra*.

2.2. Methods

2.2.1. Data Collection

Data was collected from a variety of sources such as journal papers, conference proceedings, biodiesel production experts, research reports, and the latest market price, as well as the practitioners experienced in this field in 2019. Data collection method can be found in elsewhere [53,61]. The capital cost or initial capital cost of the installation of plants for biodiesel production is generally based on the capacity of production that will be developed.

2.2.2. Life Cycle Cost

The life cycle costs (LCC) also evaluate the economic benefits of the plant. In this part, the lifecycle cost of *Ceiba pentandra* oil for biodiesel production from renewable sources of feedstocks from tropical biodiversity is developed, and it is divided into six parameters as follows:

$$LCC = CC + OC + MC + FC - SV - BP \tag{1}$$

Recently, economics and business have widely used present value calculations to compare cash flows at a different period. Implementing this method, the model for present value for life cycle cost calculations is presented by the following equation [62]:

$$LCC = CC + \sum_{i=1}^{n} \frac{OC_i + MC_i + FC_i}{(1+r)^i} - \frac{SV}{(1+r)^n} - \sum_{i=1}^{n} \frac{BP_i}{(1+r)^i} \tag{2}$$

- Present worth factor

The total estimated cost of the project that currently collected from future cash flows is called the present value factor (PWF). The investigation feasibility of the biodiesel production plant is established

by using the PWF with a selected interest rate. For the years i, PWF can be calculated by the following equation [63]:

$$PWF = \frac{1}{(1+r)^i} \tag{3}$$

Summing it over the life span of n years produces the compound present worth factor (CPW), which can be written as follows:

$$CPW = \sum_{i=1}^{n} \frac{1}{(1+r)^i} \tag{4}$$

$$CPW = \frac{(1+r)^n - 1}{r(1+r)^n} \tag{5}$$

- Capital cost

There are three categories in calculating the capital cost; namely, maximum, nominal and minimum of initial capital costs of a biofuel production plant, which is based on its production capability. These three categories to calculate the capital cost of the plant for biofuel production are determined by the following [64]:

$$CC_{high} = -517.76 \times PC^2 + 252928 \times PC + 3446300 \tag{6}$$

$$CC_{avg} = -430.13 \times PC^2 + 205235 \times PC + 2696000 \tag{7}$$

$$CC_{low} = -342.49 \times PC^2 + 157542 \times PC + 1945700 \tag{8}$$

- Operating cost

The operating costs comprise the transportation costs, factory costs, utility costs, laboratory services, supervision costs, labour costs, administrative expenses, energy flows and all other related material. The waste treatment and sewage sludge treatment is also included with the operating costs. Because production capacity is correlated with operating costs, the operating cost was determined by setting the cost per ton of biodiesel constant. Operating costs during the project period are projected as follows [63]:

$$OC = \sum_{i=1}^{n} \frac{OR \times PC}{(1+r)^i} \tag{9}$$

- Maintenance cost

The service cost and maintenance costs are considered to be the maintenance percentage ratios to the initial capital cost and assumed to be constant during the project life span. The total maintenance costs for the project life span can be determined as follows [63]:

$$MC = \sum_{i=1}^{n} \frac{MR \times CC}{(1+r)^i} \tag{10}$$

- Feedstock cost

The adjustment of yearly feedstock consumption is calculated based on the plant capacity and the feedstock conversion efficiency of biodiesel production. The total feedstock cost is the multiplication of the total annual consumption of feedstock and the feedstock cost. Therefore, the sum of the feedstock cost for the project life span can be determined by the following equation [62]:

$$FC = \sum_{i=1}^{n} \frac{FP \times FU}{(1+r)^i} \tag{11}$$

- Salvage value

The value of the remains of plant assets or components at the end of the life span of the project is known as the salvage value. The depreciation rate is expected to occur annually for this project. The model of salvage value is based on the substitution cost instead of the initial cost. This salvage value can be calculated by the following equation [62]:

$$SV = RC \times (1-d)^{n-1} \tag{12}$$

Consequently, the salvage cost of the current value can be determined by the equation below:

$$SV_{PV} = \sum_{i=1}^{n} \frac{RC \times (1-d)^{n-1}}{(1+r)^n} \tag{13}$$

- By-product credits

The biodiesel production process produces the by-product named Glycerol, which is usually sold as a useful by-product. However, the glycerol can be converted for such purposes as fuel Oxygenates (additive), Reforming Syngas, Glycerol Carbonate, Propylene glycol etc. The glycerol actually can be utilized for solvent, antifreeze, pharmaceuticals and others by the conversion of the catalyst of glycerol that has been found [65].

The fixed price for glycerol calculated based on the biodiesel production capacity, and the value of credit of by-product for the plant life span and it is calculated by the following equation:

$$BP = \sum_{i=1}^{n} \frac{GP \times GCF \times PC \times 1000}{(1+r)^i} \tag{14}$$

- Payback Period

The payback period is the time required to get back the initial investment spent. The payback period is the ratio between the capital cost, annual total biodiesel sales, the annual total production cost and annual total tax. The payback period can be determined as follows [63]:

$$PP = \frac{CC}{TBS - TPC - TAX} \tag{15}$$

Whereby,

$$TBS = \frac{BFP \times PC}{\rho} \tag{16}$$

$$TPC = 1.1 \times \frac{LCC}{n} \tag{17}$$

$$TAX = (TBS - TPC) \times TR \tag{18}$$

- Total biodiesel cost

The total biodiesel costs are a function of life cycle cost and the profit margin. The profit margin is that this study assumed to be 10% of biodiesel production cost. Therefore, in this case, the total biodiesel production determined as follows [62]:

$$TPC = 1.1 \times \frac{LCC}{n} \tag{19}$$

- Final biodiesel unit cost

The final biodiesel unit cost is calculated as a function of total biodiesel production cost usually per in cost per litre of biodiesel produced. In defining the conversion unit, the correlation between the density of biodiesel and the total biodiesel production cost over the production capability annually. Therefore, the final unit cost of biodiesel can be determined by the following equation [63]:

$$FBC = \frac{TPC \times \rho}{PC} \tag{20}$$

2.2.3. Potential Fuel Saving

There is a small difference between the calorific value of diesel and biodiesel fuels have some dissimilarity in heating value or calorific value. This difference will increase the fuel consumption of the vehicle. In this case, fuel substitution ratio between the diesel to biodiesel needs to be calculated. This ratio can be determined by the following equation:

$$SR = \frac{HVG}{HVB} \tag{21}$$

The total fuel substitution of diesel with biodiesel is a function of annual diesel consumption replacement based on substitution ratio, which can be presented by applying the equation below:

$$GR_i = \eta \times GC_i \tag{22}$$

The total required biodiesel substitution with the diesel fuel can be calculated using diesel fuel replacement times with biodiesel to the fossil diesel substitution ratio that is presented by the following equation:

$$BC_i = GR_i \times SR \tag{23}$$

The total potential fuel savings is a function of the replacement of diesel fuel and diesel fuel energy content that can be determined as follows:

$$TFS = \sum_{i}^{n} GR_i \times EC \tag{24}$$

2.2.4. Sensitivity Analysis

The sensitivity analysis is the analysis of the performance predicted that changes by changing key assumptions and predictions based on basic values. Uncertainty of prices in the international market also leads to the examination, so that it can change the project outcome. The most important variables in calculating the sensitivity analysis are the price of feedstock, operating costs, initial capital costs and discount rate. In a sensitivity analysis, the most important variable is the price of feedstock. It depends on the value of the market and is expected to be sensitive to biodiesel world prices. It can lead to two different results. The feedstock prices will tend to rise if biodiesel production capacity exceeds supply or production of the feedstocks, whereas feedstock prices will decline if the feedstock producers augment the production of feedstock above the figures of biodiesel capacity needs. If the quality of crude oil changes, the demand and supply of feedstocks also feed into the cost of production through the changes in biodiesel quality and yield.

2.2.5. Biodiesel Taxation and Subsidy Scenarios

The policy of subsidies scenario and taxation for the biodiesel fuel affected the final biodiesel price in the country. The analysis is usually a comparison of taxation and subsidy scenarios of fossil diesel and final biodiesel product prices are at different rates. The scenarios are calculated based on the total

tax exemption. Meanwhile, a subsidy is necessary for biodiesel to be competitive with the price of fossil diesel. The cost of subsidy usually is chosen depending on the existing subsidy rate of diesel fuel and petrol fuel in certain countries.

2.2.6. Potential Environmental Impact

The impact on environment calculated in this study is the emission reduction potential by replacing fossil diesel with biodiesel, the crop land use and the carbon payback period of the ecosystem.

2.3. Total Carbon Saving

The total carbon saving potential is determined as a function of the potential net emission reduced and the amount of biodiesel required. The value can be determined as follows:

$$TCS_i = NAE \times BC_i \tag{25}$$

- Cropland needed

The cropland required is determined by dividing the feedstock needed with the biodiesel produced, which can be evaluated as follows:

$$CLR = \frac{BC \times 1000}{EY} \tag{26}$$

- Ecosystem carbon payback period

The ecosystem carbon payback period is calculated by dividing the difference between the converting natural land carbons stock to become biodiesel feedstock cropland with the potential annual carbon savings of using fuel from biodiesel. This can be determined as follows:

$$CPP = \frac{LSC - BCC}{TCS/CLR} \tag{27}$$

3. Results

Based on its characteristics, Ceiba pentandra has the potential to be one of the biodiesel feedstocks in the future. This was proven by the experimental results that are tabulated in Table 1. In order to conduct the techno-economic analysis and sensitivity analysis, the properties of Ceiba pentandra have been investigated experimentally.

Table 1. Physicochemical properties of *Ceiba pentandra* biodiesel and other sources of biodiesels.

Properties	Unit	ASTM D6751 Limit	EN 14,214 Limit	CIME [66]	CPME [67]	RTME [62]	SFME [68]
Kinematic viscosity at 40 °C	mm^2/s	1.9–6.0	3.5–5.0	3.45	4.16	6.48	3.96
Density at 15 °C	kg/m^3	880	860–900	877.6	876.9	892	879.1
Flash point	°C	Min. 130	Min. 120	165.5	156.5	206.5	160.5
Pour point	°C	−15 to 16	-	2.0	2.5	−2	−3.0
Cloud point	°C	−3 to 12	-	2.0	3.0	−1	−3.0
Calorific value	MJ/kg	–	35min	41.442	40.493	40.098	40.427
Acid value	mg KOH/g	0.5 max.	0.5 max.	0.34	0.38	0.26	0.14
Copper corrosion strip	–	3 max	–	1a	1a	1b	-
Water content	%vol.	0.05 max.	500[a] max.	0.015	0.045	-	-
Sulfur content (S 15 grade)	ppm	15 max.	-	6.23	13.97	14.85	-
FAME content	%m/m	-	96.5 min	98.7	98.6	-	-

[a] mg/kg, CIME: *Calophyllum inophyllum* Methyl ester, FAME: Fatty Acid Methyl ester, RTME: *Reuteulis Trisperma* Methyl ester, SFME: *Sterculia feotida* Methyl ester.

3.1. Economic Indicators

For this task, the lifetime has been fixed for 20 years with the starting year of 2019. This consists of a year for the start-up of the plant and some constructions. For the project lifetime, the plant capacity has been estimated to operate at 100%. The calculation of the capital costs is based on the land area needed, basic equipment and instrumentation needed and the construction of the building for the plant. In this analysis, crude *Ceiba pentandra* oil was utilized as a biodiesel production sources of feedstocks. Fifty ktons of *Ceiba pentandra* crude oil are necessary to make 49 ktons of biodiesel with a total 98% biodiesel conversion yield. From this value, the selling price can be estimated for the first 10 years as 0.58 $/L and for the 11th to the end it is 2.00 $/L. The outcome from the economic data and indicators has been shown in Table 2.

Table 2. Summary of the economic data and indicators.

Input Data	Data
Year enacted	2019
Project lifetime (n. Year)	20
Interest rate (r, %)	8.0%
Plant capacity (ton/year)	50,000
Feedstock cost, S (%)	2.0%
Feedstock price ($/ton)	980
Operating cost/unit (Or, $/ton/FAME)	250
Maintenance cost/unit (Or, $/ton/FAME)	2.50%
The yield of biodiesel (FAME) conversion	98%
Feedstock price, Feedstock consumption (FP-FU, Tons)	51,020
Depreciation Model (D, %)	10%
Replacement Cost ($ Million)	10,000,000
Glycerol Conversion Factor from Feedstock Oil (Gcf, kg/Ton)	100
By Product Price ($/Ton Glycerol)	300
Glycerol Price by Product (Tons)	5102.04
By Product Price Increase Ratio (%)	0%
Tax (%)	15%
Subsidy for Biodiesel Cost ($/L) G 1	0.1
Subsidy for Biodiesel Cost ($/L) G 2	0.18
Diesel (Fossil) Selling Price ($/L)	0.58
Biodiesel Selling Price for First to Tenth Year ($/L)	0.58
Biodiesel Selling Price for Eleven To Till The End ($/L)	2
Density (kg/m^3)	877

3.2. Life Cycle Cost Analysis and Payback Period

By using a biodiesel plant with a capacity of 50 ktons located in Malaysia as tabulated in Table 2, the techno-economic analysis can be calculated. These results are shown in Figure 3 and Table 3. The Life cycle cost analysis of *Ceiba pentandra* biodiesel process production is around $701 million. Life cycle cost analysis of *Ceiba pentandra* biodiesel process can be calculated by using Equation (1), which is

$$LCC = CC + OC + MC + FC - SV - BPC \quad (28)$$

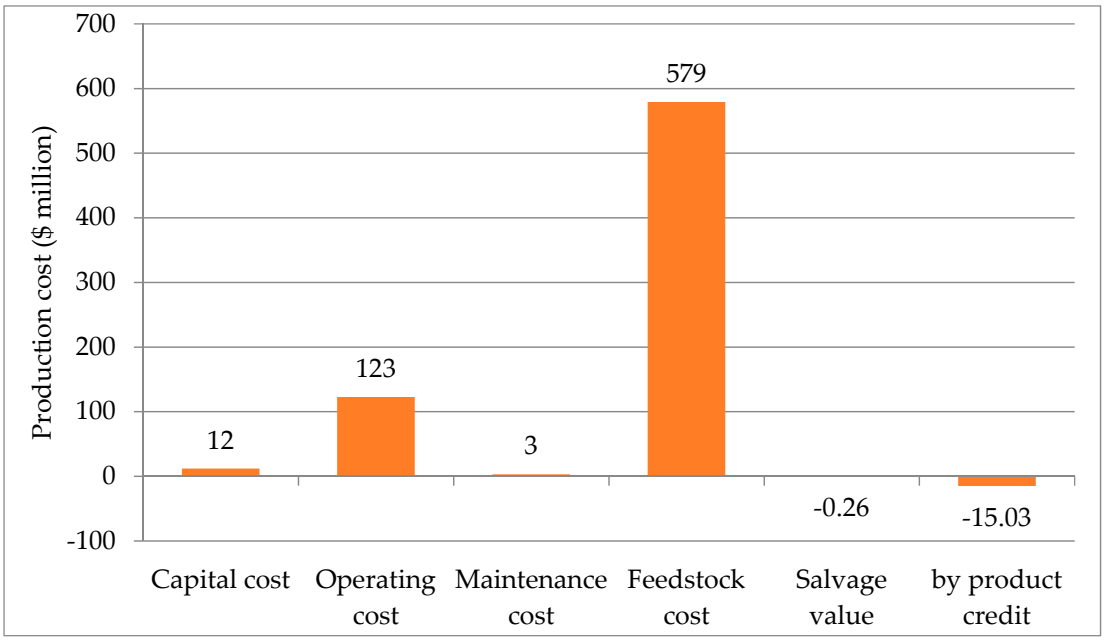

Figure 3. Distribution of *Ceiba pentandra* biodiesel production.

Table 3. Summary of total production cost and a payback period of the biodiesel production plant.

Indicator	Life Cycle Cost ($)	Unit Cost ($/L of Biodiesel)
Capital cost	11,882,425	0.0119
Operating cost	122,726,843	0.1227
Maintenance cost	2,916,585	0.0029
Feedstock cost	579,013,752	0.5790
Salvage value	260,841	0.0003
By product credit	15,027,777	0.0150
Total biodiesel cost	701,250,988	0,6765
Payback period (year)		3.7

Based on Table 2, it shows the capital cost, feedstock cost, operating cost, salvage value, maintenance cost, and credit of by-product. From that, it can be concluded that in the final biodiesel production cost, the cost of feedstock has the highest portion. The unit cost of the feedstock cost is $0.58/L. For the operating cost, the unit cost is $0.12/L. The sale of by-products gives $15 million and $0.015/L unit cost.

3.3. Potential Fuel Saving

The total diesel fuel substitution can be calculated based on an annual consumption of diesel fuel to the ratio of biodiesel substitution. The overall biodiesel required for substituting the diesel fuel is calculated by diesel fuel replacement, multiplied with diesel to biodiesel substitution ratio. In view of the fact that diesel and biodiesel fuels have some similarity in heating value. Therefore, some additional amount of biodiesel fuels is required to replace the higher heating value of diesel fuel. The fossil diesel consumption and potential diesel replacement are tabulated in Table 4.

Table 4. Fossil diesel consumption and potential diesel replacement.

Year	Diesel Consumption		Diesel Replacement/Saving	
	(Million Litres)	(Tons)	(Million Litres)	(Tons)
2019	8778	8,526,812	509	426,341
2020	9020	8,761,778	523	438,089
2021	9261	8,996,743	537	449,837
2022	9503	9,231,709	551	461,585
2023	9745	9,466,675	566	473,334
2024	9987	9,701,641	580	485,082
2025	10,229	9,936,607	594	496,830
2026	10,471	10,171,573	608	508,579
2027	10,713	10,406,539	622	520,327
2028	10,955	10,641,505	636	532,075
2029	11,197	10,876,471	650	543,824
2030	11,438	11,111,437	664	555,572
2031	11,680	11,346,403	678	567,320
2032	11,922	11,581,369	692	579,068
2033	12,164	11,816,335	706	590,817
2034	12,406	12,051,301	720	602,565
2035	12,648	12,286,267	734	614,313
2036	12,890	12,521,233	748	626,062
2037	13,132	12,756,198	762	637,810
2038	13373	12,991,164	776	649,558

3.4. Sensitivity Analysis

The sensitivity analysis results can be figured out in Figure 4. This consists of five input variables such as initial capital cost, operating rate, conversion yield of oil, discount rate and the feedstock price. The difference in the price of the feedstock is corresponding to the main impact of the life cycle cost. For instance, the crude oil price of *Ceiba pentandra* is $680/ton that decreases the life cycle production cost to $524 million as presented in Figure 4. However, if the price of CCPO rises to $1280/ton, the life cycle cost of biodiesel production will rise to $878 million. As for the discount rate increase by 10% per year, it will affect a 13% decrease in the total life cycle cost of biodiesel production. The operating rate of $175/ton only affected the total life cycle production cost to $664 million as well as operating cost of $325/ton will change the total life cycle cost of biodiesel production to $738 million. Crude oil prices for biodiesel feedstocks have been observed over the past two years. The oil conversion and industrial operating costs are the last that affected on-going cost, but both costs can offset the fluctuation of feedstock prices. In addition, the production costs can still be reduced by improvements in the conversion process of biodiesel production.

Figure 5, shows the feedstock price fluctuation on biodiesel production cost for *Ceiba pentandra*. The differences in operating cost and oil conversion yield have the least impact on running cost. However, both can counteract important variation in the feedstock price. By continuously improving the conversion processes of biodiesel and higher operating efficiency, it can decrease the whole biodiesel production cost significantly. In addition, the effect of the price fluctuation of *Ceiba pentandra* crude oil was additionally investigated.

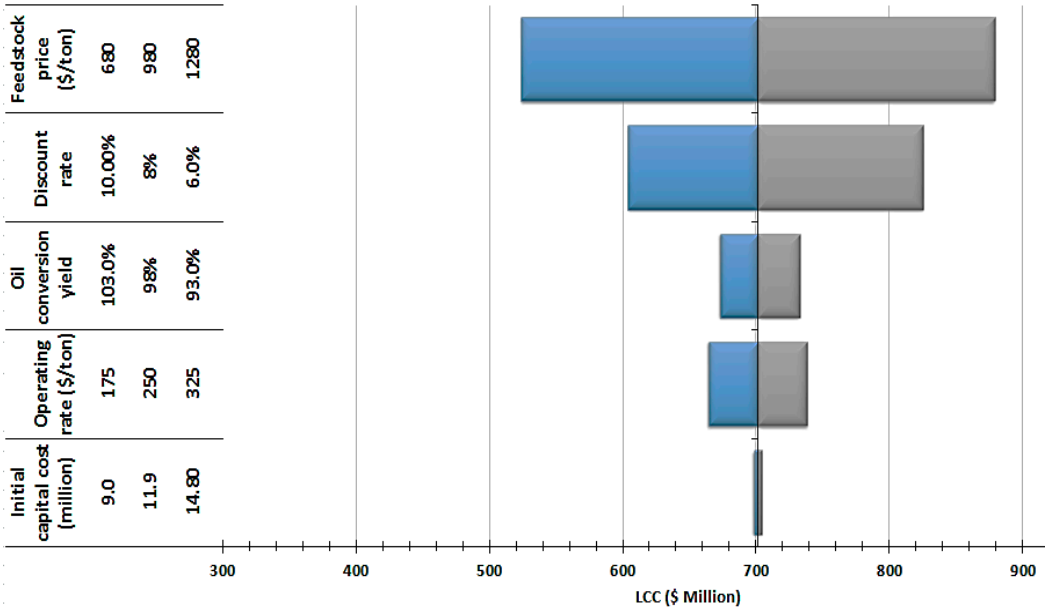

Figure 4. Sensitivity analysis of life cycle costs for *Ceiba pentandra* biodiesel production.

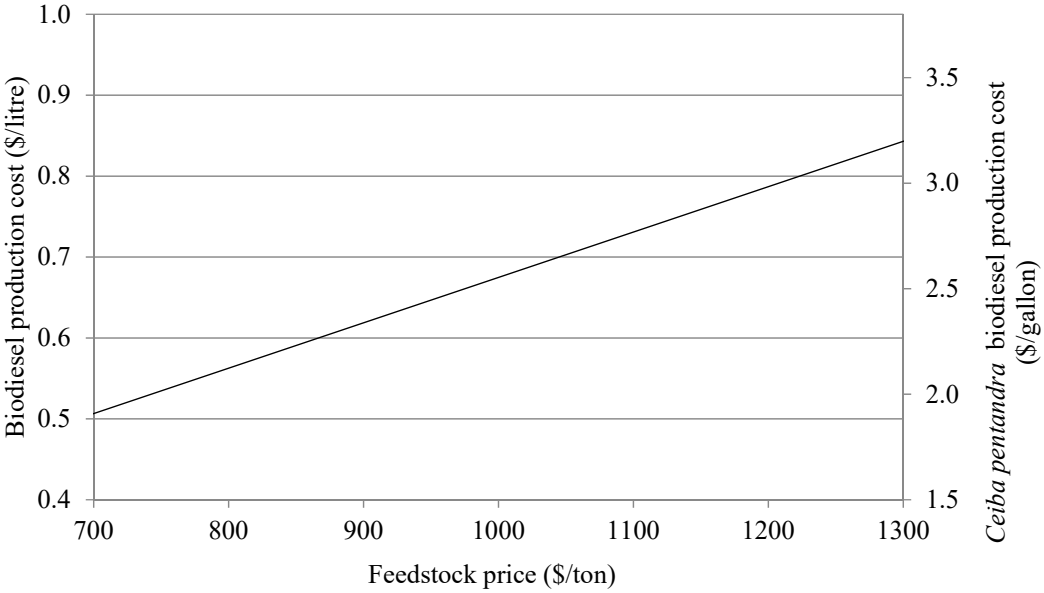

Figure 5. The impact of feedstock oil price on the biodiesel production cost.

3.5. Biodiesel Taxation and Subsidy Scenarios

Subsidy and taxation scenarios are necessary for the final cost of biodiesel and it is tabulated in Table 5. Based on Table 5, it explains the differences of final biodiesel price with petrol diesel at various scenarios of subsidy and taxation, such as total tax exemption 15%, $0.10/L subsidy and lastly $0.18/litre for biodiesel compared to the price of fossil diesel. The subsidy cost was fixed at $0.10/L and $0.18/L. This was being set based on the latest cost of subsidies and diesel price in this country. From Table 5, with a subsidy, it is possible to match the total cost of biodiesel and fossil diesel price.

Table 5. Biodiesel taxation and subsidy level scenarios at current production cost.

$/L	Biodiesel				Fossil Diesel
	Total Tax Exemption	15% of Tax	Subsidy ($/L) 0.10	Subsidy ($/L) 0.18	
Biodiesel cost	0.676	0.676	0.676	0.676	-
Taxes/subsidy	0	0.101	0.100	0.180	-
Total	0.676	0.778	0.576	0.496	0.581
Total cost	0.687	0.790	0.586	0.504	0.581

The breakeven price of biodiesel from *Ceiba pentandra* of various crude petroleum oil price and crude *Ceiba pentandra* oil is presented in Figure 6. There are two parts of Figure 6; the first part is an area on the top of the line that represents the subsidy required for replacement of diesel fuel with *Ceiba pentandra* biodiesel fuel, while in the lower area of the line is the part of potential savings generated by substitution. For example, when the crude oil prices are $ 100/barrel, the price of biodiesel fuels is equivalent to diesel at CCPO price $1585/ton. Then, if the CCPO price increases above $1585/ton, the subsidies are needed to keep the use of biodiesel still running. However, if the CCPO price decreased below $1585/ton, it will result in cost savings by replacing diesel fuel with biodiesel fuel.

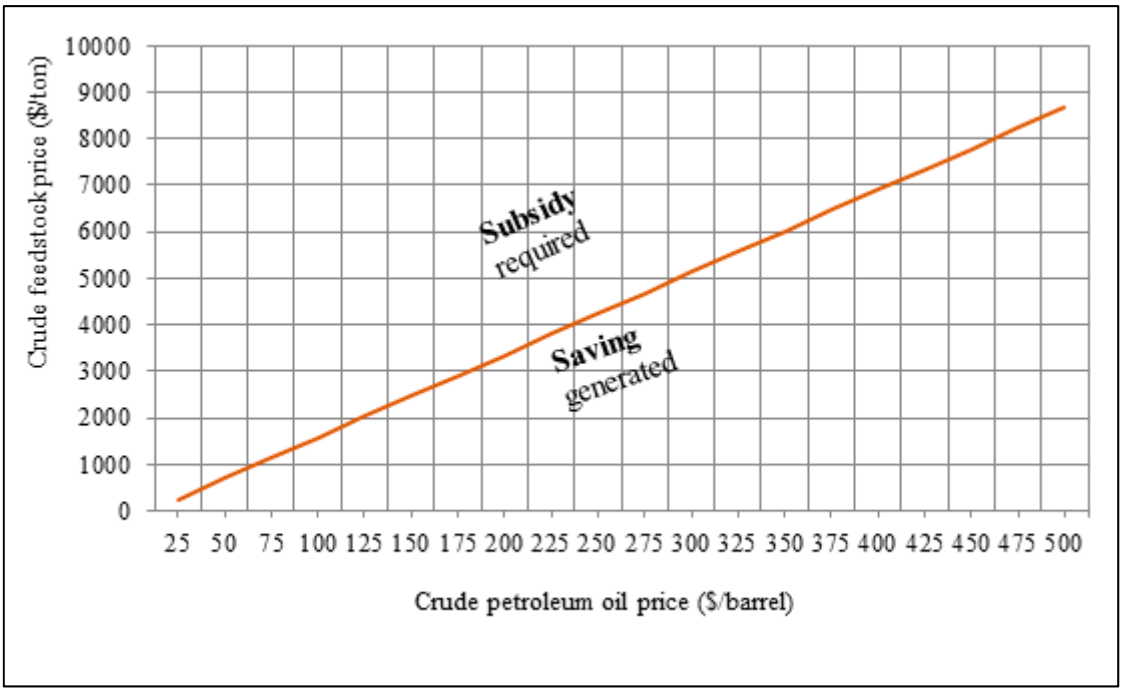

Figure 6. The breakeven price for biodiesel production at different petroleum and feedstock prices.

Figure 7 illustrates the taxation and subsidy scenarios of the biodiesel production cost of feedstock price of *Ceiba pentandra*. Based on the graph, the biodiesel price is very competitive with fossil diesel. This happened when the feedstock prices are below $1/kg, the price of biodiesel can compete with fossil diesel with tax exemption. The subsidized required for biodiesel are from $0.10/L and $0.18/L, the competitiveness of feedstock prices for biodiesel with fossil diesel can reach about $1/kg and $1.17/kg, respectively. However, when the feedstock prices increase up to $1.17/kg, the biodiesel price can be higher than fossil diesel even though biodiesel has been given a subsidy of $0.18/L. These are necessary in order to make biodiesel competitive with fossil diesel.

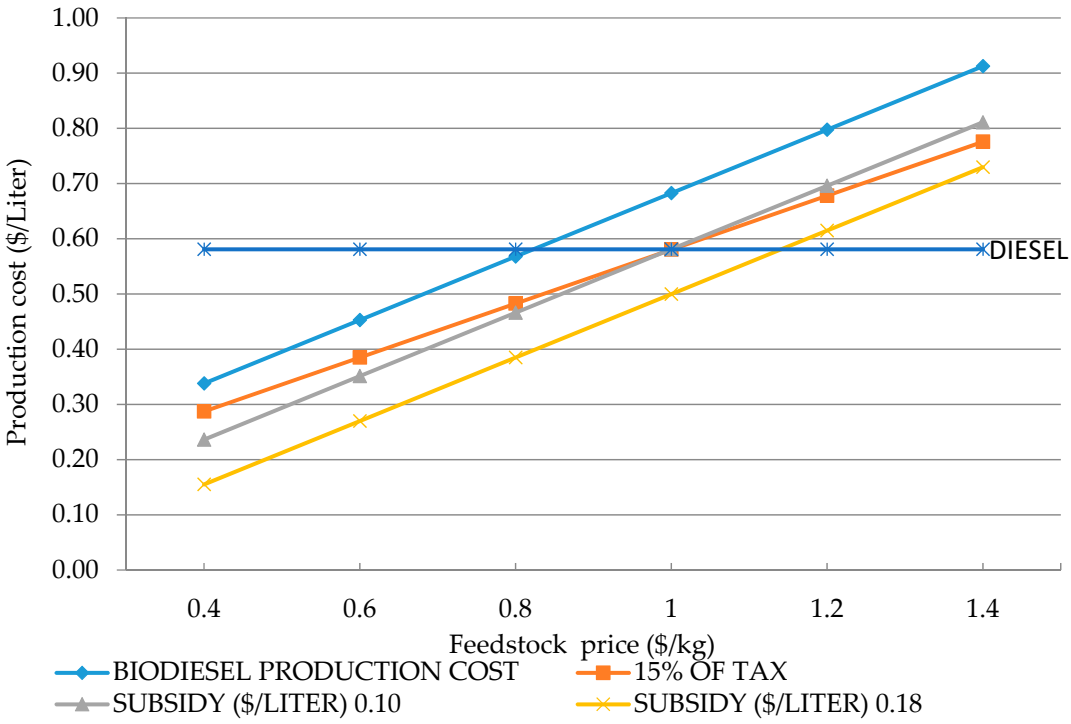

Figure 7. Taxation and subsidy scenarios of biodiesel production cost on feedstock price.

3.6. Potential Environmental Impact

The outcomes of the environmental impacts presented are probable emission reductions, and cropland has been used for the feedstock of biodiesel and an environment carbon payback period. To calculate the carbon saving potential, the net avoided emission should be multiplied by the amount of biodiesel required. The needed cropland is based on the need for feedstock for biodiesel production. Meanwhile, to estimate the ecosystem carbon payback period, dividing the difference of the carbons stock and the natural land changing to cropland for biodiesel production. The outcomes tabulated in Table 6 presents the cropland for biodiesel feedstock with the annual carbon savings by utilizing fuel from biodiesel. An increase in the use of biodiesel to replace fossil diesel causes an increase in the amount of biodiesel needed to simplify the substitution of biodiesel to fossil diesel. Along with the increased biodiesel demand, the need for feedstocks to supply biodiesel fuel requires more agricultural land to supply biodiesel feedstock. Diesel substitution rates of 1%, 25% and 50% require land of 28 kHa, 707 kHa and 1414 kHa, respectively. From Figure 8, it shows the differentiation of overall carbon emissions by biodiesel and fossil diesel fuel. From Figure 8, it can be seen that even with the replacement of diesel, total carbon emission will still increase, but this increase is less than the increase accounted for diesel. It is because the carbon emission factor in fossil diesel is higher than biodiesel. The differences in carbon emissions between fossil diesel provide benefits to biodiesel so as to save total carbon by diesel substitution and make biodiesel more efficient with lower pollution levels. The fossil diesel substitution rate of 1% results in total energy savings from diesel of 3,675,056 MJ and total carbon saving of 129,356 kg, and at the diesel replacement rate of 50%, total energy savings from diesel and total carbon saving are 183,752,790 MJ and 6,467,798 kg, respectively Table 6.

Table 6. The results, by changing the number of replacements for cropland required, total energy saving and total carbon saving.

Diesel Consumption	Diesel Replacement Rate	Diesel Replacement Rate	Biodiesel Needed	Cropland Required	Total Energy Saving (Diesel)	Total Carbon Saving
DC		DR	BC	CLR	TES	TCS
8,526,812 (TONS)	(%)	(TONS)	(TONS)	(HA)	(GJ)	(KG)
2019	1%	85,268	90,765	28,297	3,675,056	129,356
2020	2%	170,536	181,529	56,594	7,350,112	258,712
2021	3%	255,804	272,294	84,892	11,025,167	388,068
2022	4%	341,072	363,058	113,189	14,700,223	517,424
2023	5%	426,341	453,823	141,486	18,375,279	646,780
2024	6%	511,609	544,587	169,783	22,050,335	776,136
2025	7%	596,877	635,352	198,081	25,725,391	905,492
2026	8%	682,145	726,116	226,378	29,400,446	1,034,848
2027	9%	767,413	816,881	254,675	33,075,502	1,164,204
2028	10%	852,681	907,645	282,972	36,750,558	1,293,560
2029	15%	1,279,022	1,361,468	424,459	55,125,837	1,940,339
2030	20%	1,705,362	1,815,291	565,945	73,501,116	2,587,119
2031	25%	2,131,703	2,269,113	707,431	91,876,395	3,233,899
2032	30%	2,558,043	2,722,936	848,917	110,251,674	3,880,679
2033	35%	2,984,384	3,176,759	990,403	128,626,953	4,527,458
2034	40%	3,410,725	3,630,581	1,131,890	147,002,232	5,174,238
2035	45%	3,837,065	4,084,404	1,273,376	165,377,511	5,821,018
2036	50%	4,263,406	4,538,226	1,414,862	183,752,790	6,467,798

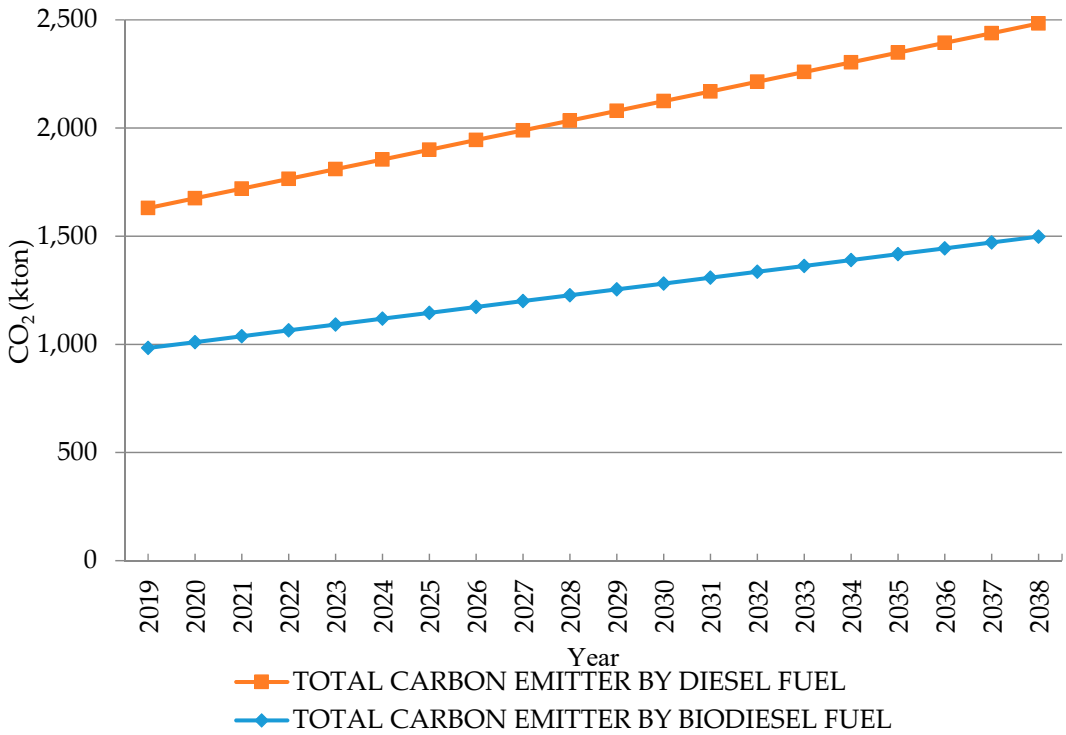

Figure 8. Total carbon emitter by diesel fuel and biodiesel fuel.

4. Conclusions

In this paper, the life cycle cost and sensitivity analysis of *Ceiba pentandra* as non-edible sources of feedstock for future production of biodiesel in Malaysia were conducted. The analyses were based on a biodiesel production plant of 50 ktons with an estimated 20-year plant lifespan. The main variables

of life cycle cost analysis such as feedstock cost, operating cost, capital cost, maintenance cost, salvage value and credit of by-product were determined. *Ceiba pentandra* biodiesel physicochemical properties are within the standard limits. The cost of feedstock has the highest portion of the total biodiesel production cost. The calculation shows that, from the year 2019 to 2038, the most of cost was spent for feedstock, which is $579 million, following by operating cost, capital cost and maintenance cost which are around $123 million, 12 million and 3 million, respectively. From the calculation, the life cycle cost of the *Ceiba pentandra* is about $701 million over the lifespan of the project. The sensitivity analysis shows that if the price of CCPO increases to $1280/ton, the life cycle cost of biodiesel production will be increased to $878 million, and whereas for the discount rate increase by 10% per year will produce 13% decrease in the total life cycle cost of biodiesel production. To be conclude, biodiesel production price only well-matched with diesel fuel if the tax and subsidy are applied. The further study of the biodiesel production should be applied more and more practically. This can help to increase the usage of biodiesel in Malaysia.

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Nomenclatures

BC	Biodiesel needed (tons)
BCC	Carbon stock for biodiesel cropland (ton/ha)
BFP	Biodiesel fuel price ($/L)
BP	By-product credits ($)
CC	Capital cost ($)
CLR	Cropland required (ha)
CPP	Carbon payback period (year)
CPW	Compound present worth factor ($)
CCPO	Crude *Ceiba pentandra* oil
d	Depreciation cost
EC	Energy content of diesel fuel (GJ/ton)
EY	Ethanol yield (kg/ha)
FBC	Final biodiesel unit cost ($/L)
FC	Feedstock cost ($)
FP	Feedstock price ($)
FU	Feedstock consumption (tons)

GC	Diesel consumption (tons)
GCF	Glycerol Conversion Factor ($)
GP	Glycerol Price ($)
GR	Diesel replacement (tons)
HVB	Heating value of biodiesel fuel (MJ/kg)
HVG	Heating value of diesel fuel (MJ/kg)
i	Project year (year)
LCC	Life cycle cost ($)
LSC	Carbon stock for natural forest (ton/ha)
MC	Maintenance cost ($)
MR	Maintenance rate (%)
NAE	Net emission reduction
n	Project life time (year)
η	Fossil diesel replacement rate (%)
OC	Operating cost ($)
OR	Operating rate ($/ton)
PC	Annual Biodiesel Production Capacity (tons/year)
PP	Payback Period (year)
PV	Present Value
ρ	Density (kg/m^3)
r	Discount rate (%)
RC	Replacement cost ($)
SR	Substitution ratio of biodiesel to diesel fuel (%)
SV	Salvage value ($)
TAX	Annual total tax ($/year)
TBS	Annual total biodiesel sales ($/year)
TCS	Total carbon saving (tons)
TFS	Total potential fuel saving
TPC	Annual total production cost ($/year)
TR	Tax ratio (%)
$	All monetary unit is in US dollar
EN	European standard
ASTM	American Society for Testing and Materials
CPME	Ceiba pentandra methyl ester

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