Techno-economics analysis of biodiesel production from palm, *jatropha curcas* and *calophyllum inophyllum* as biofuel

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Abstract. Transportation sector has a dominant role in global fuel consumption and greenhouse gas emissions consequently. Biodiesel is a renewable energy that has great potential to serve as an alternative fuel to fossil diesel in diesel engine. Besides the technical barriers, there are several nontechnical limiting factors, which impede the development of biodiesel. Therefore, this study is focused on biodiesel production and techno-economic comparison among palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel as transportation fuel. Moreover, the present study attempts to find out the impact of biodiesel implementation towards the energy scenario, environmental and economy. The largest economic factor for biodiesel production is feedstock cost. Furthermore, replacing 5% of diesel fuel with biodiesel fuel in road transport can reduce the CO_2 emission up to 1200 ktons in year 2031. When the subsidy policy and tax exemption are implemented, biodiesel fuel is more competitive than fossil diesel at the current production costs. Therefore, this study serves as a guideline for further investigation on biodiesel production and other limitation factors before the wider utilization of biodiesel can be implemented.
Keywords: Biodiesel; Alternative Energy; Emission; Road transport; Techno-economic.

Introduction

Abundant and economical energy are the life blood of modern civilizations. However, the global energy consumption is growing faster than the increase in the population. The fuel consumption increased from 6,630 million tons of oil equivalent (Mtoe) in 1980 to 11,295 Mtoe in 2008 (British Petroleum, 2008). It is forecasted by International Energy Agency that the global energy consumption would increase 53% by 2030. The fossil fuels have significantly contributed to emission production and the climate change. Carbon dioxide (CO_2), nitrogen oxide (NO), volatile organic compounds (VOC) and hydrocarbons (HC) are the main air pollutants which are resulted from the fossil fuels combustion. Therefore, the greenhouse gas mitigation strategies are taken into consideration in recent efforts on the development of global environmental issues, research and urban planning.

Biodiesel is one of the significant solutions for oil shortage and global warming. Through the transesterification process of the vegetable oils, animal fats or recycled greases can be converted into biodiesel. It is a clean and renewable fuel which is suitable as the alternative fuel for fossil diesel. Biodiesel industry is still in its infancy but is growing rapidly. The world total biodiesel production in 2007 was reported to be 8.4 million tons which increased to 20 million tons in 2010 and it is predicted to reach 150 million tons by 2020 (Agra CEAS Consulting, 2010). However, variability in the feedstock, fossil fuel price and the demand of biodiesel have given rise to instability within the industry (Sotoft *et al.*, 2010). These factors have influenced the economic viability of biodiesel at a global scale. Currently, 95% of the world biodiesel production is from edible oil that is easily available on a large scale from the agricultural industry. Since there is a competition between the food and fuel market, this makes the focus is shifted to non-edible oil like *jatropha curcas, pongamia, calophyllum* as feedstock for biodiesel production (Gui *et al.*, 2008; Tan *et al.*, 2009).

Malaysia as one of the biggest producers of biodiesel fuel has started the development of biodiesel from palm oil since the 1980s. However, the commercialization and utilization of biodiesel as transportation fuel has not been fully undertaken on a large scale in this country. Besides the technical factors, there are several non-technical limiting factors such as feedstock price, biodiesel production cost, crude oil price, issue of food and fuel, limited land available as well as policy issue such as taxation and subsidy which slow down the development of biodiesel (Enguidanos *et al.*, 2002). The major obstacles in commercializing biodiesel is the high economic cost of production compared to fossil fuel (Yusuf *et al.*, 2011). Among these factors, no matter how much biodiesel production processes are improved, the feedstock cost is still major component of production costs.

There are insufficient studies conducted on the techno-economic analysis and feasibility of biodiesel fuel in Malaysia Therefore, the primary objective of this study is to assess the biodiesel production and the economic feasibility of applying palm, *jatropha curcas* and *calophyllum inophyllum* as biofuel. After that, the comparison analysis among palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel fuel is also formulated in three aspects which are energy, emission and economic scenarios. This study can present a guideline for further investigation on implementation of non-edible biodiesel as transportation fuel.

Materials and Methods

Biodiesel production process

Materials

The crude palm oil, *jatropha curcas* and *calophyllum inophyllum* oil were shown in Figure 1. The crude palm oil, *jatropha curcas* oil and *calophyllum inophyllum* oil were analyzed based on their density at 15^{o}C, viscosity at 40^{o}C, flash point, acid value, free fatty acid and fatty acid composition.

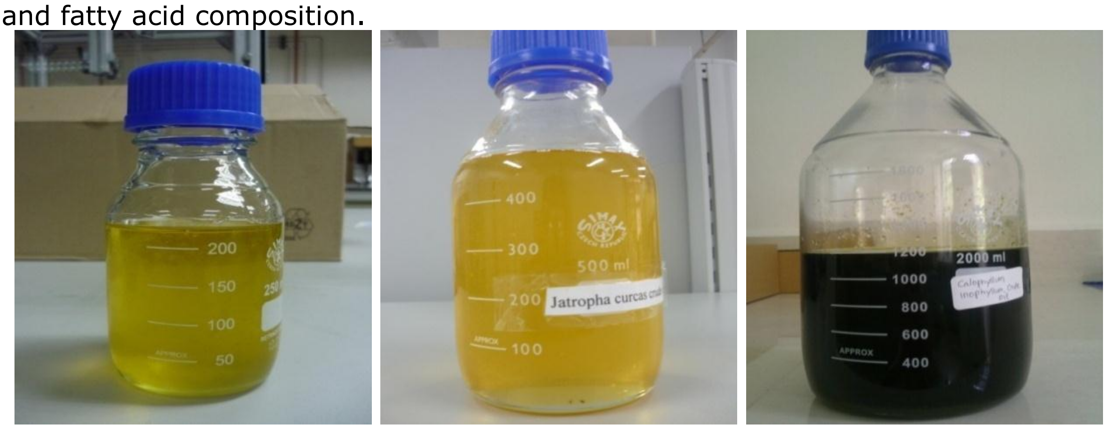

Figure 1. Photo of crude palm oil (left), crude *jatropha curcas* oil (center) and crude *calophyllum inophyllum* oil (right).

Degumming of crude oil

Gum contains phosphate, protein, carbohydrate, water residue and resin. In order to improve the oxidization stability of the final product, the oil is separated from the gums through the degumming process. In this process, the crude oil was heated at a temperature of 60°C and string speed of 1000 rpm. Then, 0.5% (v/v) of phosphoric acid (H_3PO_4, 30% concentration) was added to the preheated crude oil. The process was continued with stirring and the temperature maintained at 60^{o}C for 30 minutes.

Pre-treatment process (Acid-catalyzed esterification process)

The vegetable oils especially the non-edible oils such as crude *jatropha curcas* and *calophyllum inophyllum* oil have high content of free fatty acid (FFA). High amount of free fatty acid (2% wt of FFA and above) in the crude vegetable oil will react undesirably with the alkali catalyst and cause the formation of soap. This formed soap could prevent separation of the methyl ester layer from the glycerine fraction. The maximum limit of FFA amount is 2% wt and below. Therefore, a pre-treatment process using acid catalyzed esterification is required for the crude oil with high FFA content before the transesterification process.

On top of that, the crude *jatropha curcas* oil and *calophyllum inophyllum* oil were measure and entered into a jacketed reactor. Then, crude oil was preheated to the temperature of 55-60°C by using a heating circulator. Figure 2 shows the utilized experimental set up of the esterification process in this study. The desired amount of methanol and HCl catalyst were measured and mixed together before added into the reactor. The added amounts of methanol vary from 10% to 30% (v/v). However, the added amount of HCl catalyst was in a range of 0.5 to 1.0% (v/v). The mixture was stirred constantly using an overhead stirrer with a constant speed of 1200rpm during the process for 2 hours. Throughout this process, the temperature was kept constant at 55°C. After esterification process the sample oil was removed from the reactor and entered into a separation funnel for 4 hours to remove the water and extra methanol. The upper layer is esterified oil while the water was formed during the reaction process and extra methanol at the lower layer.

Transesterification process of oil

Transesterification methods are used in this study to convert the crude vegetable oil into fatty acid methyl ester (FAME) which is biodiesel. The crude oil was measured and placed into a jacketed reactor. Then, crude oil was preheated to the temperature of 55-60°C by using a heating circulator. The exact quantity of alkali catalyst (KOH) and methanol are mixed until all the KOH has been dissolved. After that, the prepared mixtures of methanol and alkali catalyst (KOH) were added into the preheated crude oil. The mixture was stirred constantly at 1200rpm by an overhead stirrer during the transesterification process for 1 to 2 hours. In this process, the temperature was maintained at around 55°C. The experimental setup for transesterification is shown in Figure 2. The details of the carried out transesterification process in the present study are listed in Table 1. After completion, the mixture was placed into a separating funnel for 4 hours to ensure that the separation of methyl ester and glycerine phase by gravity occurred completely. The upper layer was the biodiesel while the lower layer which contained impurities, extra methanol and glycerine were removed.

Figure 2: Experimental setup of esterification and transesterification process.

Table 1. The detail of transesterification process

Crude oil	Alkaline catalyst	Time (min)	Temperature (°C)	Methanol (% v/v)	Catalyst (% w/w)
Palm oil	KOH	60-120	50-60	10-20	0.5-1%
Jatropha curcas	KOH	60-120	50-60	10-20	0.5-1%
Calophyllum inophyllum	KOH	60-120	50-60	10-30	0.5-1%

Post-treatment process

After phase separation of FAME and glycerine, the FAME contains residual catalyst, glycerine, soap, methanol and water. The FAME was purified and washed gently with distilled water at 40°C in order to remove impurities. The mixture was allowed to settle under gravity for 3-4 hours in a separating funnel. The settled layer of mixture with impurities was drained out. After the washing process, the final product was evaporated with rotary evaporator at 65°C for 30 minutes to remove residual methanol and water. The flow chart methodology for biodiesel production is show in Figure 3.

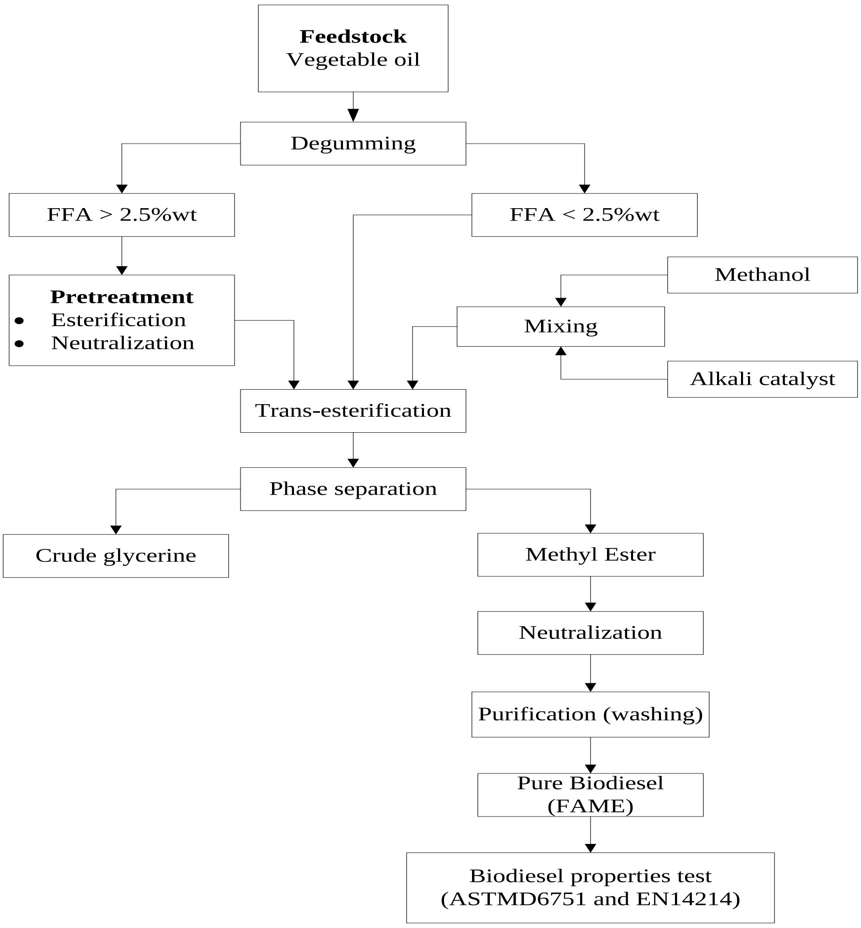

Figure 3: Flow chart of biodiesel production process.

Life cycle cost and payback period

Life cycle cost

Life cycle cost analysis is the total cost of ownership of a plant or system by evaluating the economic benefit of the plant. In this section, life cycle cost model for biodiesel production plant is developed and grouped into six categories. By applying the following approach, the present value calculations are widely used in business and economics to compare cash flows at different times. Writing the life cycle cost in the form of a present value model yields,

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

Capital cost

The required land area, building construction, equipment and instrumentations for the biodiesel plant are taking into account in capital cost. Capital cost of the initial installation depends mainly on the biodiesel plant capacity. Based on the study by Howell (Howell, 2005) the highest, average and lowest initial capital costs of biodiesel plant based on plant capacity can be expressed in the following equation:

$$CC_{high} = -517.76 \times PC^2 + 252928 \times PC + 3446300 \quad (2)$$

$$CC_{avg} = -430.13 \times PC^2 + 205235 \times PC + 2696000 \quad (3)$$

$$CC_{low} = -342.49 \times PC^2 + 157542 \times PC + 1945700 \quad (4)$$

Operating cost

Operating cost includes the cost of labour, utilities, laboratory services, factory expenses, supervision, administration, transportation cost, all other materials and energy flows except those related to the crude feedstock oil (e.g. CPO, CJO and CBO). Operating costs also include the costs associated with waste water treatment and sludge waste processing to remove residual acids and any other contaminant (e.g. methanol and NaOH). Given their dependence on production capacity, operating costs are calculated by setting a fixed cost per ton of biodiesel produced. Over the life of the plant, total operating costs are,

$$OC = \sum_{i=1}^{n} \frac{OR \times PC}{(1+r)^i} \quad (5)$$

Maintenance cost

The annual periodical maintenance and service cost is assumed to be a percentage of maintenance ratio to the initial capital cost. This value is considered to be constant over the entire project lifetime. Maintenance costs are calculated over the life time of the plant as,

$$MC = \sum_{i=1}^{n} \frac{MR \times CC}{(1+r)^i} \quad (6)$$

Feedstock cost

The estimation of feedstock cost is based on the total feedstock consumption for biodiesel production process. Therefore, annual feedstock consumption is determined by adjusting the plant capacity by the feedstock to biodiesel conversion efficiency. The feedstock total consumption can be estimated using the following equation:

$$FU = \frac{PC}{CE} \quad (7)$$

The price of feedstock such as crude palm oil, *jatropha curcas* oil and *calophyllum inophyllum* oil varies over time. In the present study, feedstock prices are estimated considering the historical market price as a reference and an increment with the annual growth rate. Thus, feedstock price is a function of feedstock reference price multiplied by an annual growth rate over the year. This can be represented by the following equation:

$$FP_i^e = RP_i^e \times (1 + s^e)^{i-1} \quad (8)$$

The total feedstock cost is the multiplication of the total annual feedstock consumption and feedstock price on the specific year. Based on this price, total cost of the feedstock over the life of the plant is given by,

$$FC = \sum_{i=1}^{n} \frac{FP_i \times FU}{(1+r)^i} \quad (9)$$

Salvage value

The salvage value is the remaining value of the components and assets of biodiesel production plant at the end of the project lifetime. In this study, it has been assumed that a depreciation rate occurs annually. The salvage value model is based on the replacement cost rather than the initial capital cost. The salvage value can be expressed by the following equation:

$$SV = RC \times (1 - d)^{n-1} \quad (10)$$

Thus, the present value of salvage cost can be calculated as:

$$SV_{PV} = \frac{RC \times (1-d)^{n-1}}{(1+r)^n} \quad (11)$$

By product credit

Glycerine is the by-product generated during biodiesel production process. It can be sold as a useful by-product. Calculation is based on the price of glycerine and its production volume which is determined by a plant capacity with glycerine conversion factor. Thus, the by-product credit is the multiplication of glycerine price with the glycerine produced. And, the by-product credit value over the life of the plant is given by,

$$BP = \sum_{i=1}^{n} \frac{GP \times GCF \times FU}{(1+r)^i} \quad (12)$$

Payback period

Payback period is the time taken to gain a financial return equal to the original investment cost, with the aid of which the viability and feasibility of the investment can be evaluated. The payback method uses the ratio of capital cost over annual earning as an approach to monitor the project. Taxes are included as a percentage of total biodiesel sales. The payback period is calculated by the following equations:

$$PP = \frac{CC}{TBS - TPC - TAX} \quad (13)$$

Whereby,

$$TBS = \frac{BFP \times PC}{\rho^{e}} \quad (14)$$

$$TPC = 1.1 \times \frac{LCC}{n} \quad (15)$$

$$TAX = (TBS - TPC) \times TR \quad (16)$$

Total biodiesel cost

Final biodiesel costs include the total life cycle cost, distribution cost and profit margin. The total distribution cost and profit margin are 10% of biodiesel production cost. The total biodiesel cost can be estimated using the equation below:

$$TPC = 1.1 \times \frac{LCC}{n} \quad (17)$$

Final biodiesel unit cost

Final biodiesel unit cost is the total biodiesel cost converted into $ per litre of biodiesel fuel. The conversion unit is a function of total biodiesel cost and density of biodiesel divided by annual production capacity. The final biodiesel unit cost can be expressed by the following equation:

$$FBC = \frac{TPC \times \rho}{PC} \quad \text{….. (18)}$$

Results and Discussion

The required survey data of the road transportation and fuel consumption were collected from the department of road transport (Department of Road Transport, 2008), Malaysia Energy Agency (Malaysia Energy Centre, 2008) and the department of statistic (Department of statistics, 2008). The lifetime of the project has been set to be 20 years by considering one year of construction and start up of the plant. The plant was assumed to operate in 100% capacity during the entire project's lifetime. The initial capital is considered to be paid by private investment and no loans have been taken into account. It is assumed that the selling price of the produced biodiesel and glycerine does not vary over time. Table 2 shows the summary of economic data and indicators.

Table 2. Summary of economic data and indicators.

Item	Data
Project lifetime	20 years
Plant capacity	50 ktons
Depreciation model	10% annually
Operating rate:	
Palm biodiesel	$250/ton of FAME
Jatropha curcas biodiesel	$300/ton of FAME
Calophyllum inophyllum biodiesel	$300/ton of FAME
Maintenance cost	2% of capital cost annually
Replacement cost	$10 Million
Tax ratio	15% of biodiesel profit
Glycerine price	$ 0.25/kg
Discount rate	8%

Diesel and biodiesel fuel's properties such as calorific value, density, LCA carbon factor and related conversion yield are shown in this section. The life cycle assessment of carbon emission of biodiesel fuel includes the production of the feedstock, transesterification process as well as the combustion phase of biodiesel fuel. All the input data for this study are summarized in Table 3.

Table 3. Summary of diesel and biodiesel fuel properties

Property	Diesel	Palm Biodiesel	*Jatropha curcas* bioidesel	*Calophyllum Inophyllum* biodiesel
Nett calorific value (MJ/kg)	43.4	35.0	38.5	39.3
Density (kg/m^3)	837	879	862	869
LCA carbon emission factor[1] (kg/GJ)	88.0	61.8	42.2	64.4
Yield of FAME (biodiesel) conversion	-	90	87	85
Yield of glycerine produce	-	9%	10%	5%
Vegetable oil yield[1] (kg/ha)		3740	1590	4680

Sources: (Atadashi *et al.*, 2010; Sahoo & Das, 2009; Sathya *et al.*, 2011)

Biodiesel production
Characterization of crude vegetable oil

The crude vegetable oils used in this study were palm, *jatropha curcas* and *jatropha curcas* oil as shown in Figure 1. The characteristics and the physicochemical properties of these three crude oils such as density, flash point, viscosity, acid value and free fatty acid composition were determined and shown in Table 4. These three crude vegetable oils have high viscosity which is recorded to be 41.63, 28.35 and 53.17 cSt respectively. Besides, the acid value of *jatropha curcas* and *calophyllum inophyllum* oil was above 4 mg KOH/g, measuring at 46.8 and 59.3 mg KOH/g respectively. Thus, a two-step catalyzed process was needed to produce the biodiesel fuel from crude *jatropha curcas* and *calophyllum inophyllum* oil. Furthermore, it has been found that the crude *jatropha curcas* and *calophyllum inophyllum* oil contain a higher amount of unsaturated fatty acids (oleic and linoleic) than saturated fatty acids (palmitic and stearic). Palmitic and oleic are the dominant fatty acids in the crude palm oil whilst oleic and linoleic are the dominant fatty acids in crude *jatropha curcas* and *calophyllum inophyllum* oil.

Table 4. Physicochemical properties of crude palm, *jatropha curcas* and *calophyllum inophyllum* oil

Parameters	Palm oil	*Jatropha curcas* oil	*Calophyllum inophyllum* oil
Density 15°C (kg/m^3)	0.919	0.915	0.951
Viscosity at 40°C (cSt)	41.63	28.35	53.17
Flash point (°C)	181	170	148
Free fatty acid (%FFA)	0.424	23.382	29.661
Acid Value (mg KOH/g)	0.848	46.764	59.332
Fatty acid composition (FAC)			
Lauric (12:0)	0.2	0.0	0.0
Myristic (14:0)	0.9	0.1	0.0
Palmitic (16:0)	38.6	13.0	14.7
Palmitoleic (16:1)	0.2	0.7	0.3
Stearic (18:0)	4.4	5.8	13.2
Oleic (18:1)	44.6	44.5	46.1
Linoleic (18:2)	10.5	35.4	24.7
Linolenic (18:3)	0.2	0.3	0.2
Arachidic (20:0)	0.4	0.2	0.8
Saturated	44.5	19.1	28.7
Unsaturated	55.5	80.9	71.3
Total	100.0	100.0	100.0

Acid catalyzed esterification process

The FFA for crude *jatropha curcas* and *calophyllum inophyllum* oil are 23.38% and 29.66% respectively. The crude *jatropha curcas* oil with high FFA content initially undergoes the hydrochloric acid (HCl) catalyzed esterification to reduce the FFA amount to below 2%. The esterification process was done using 1% v/v of HCl and 20% v/v of methanol in oil at 60°C. The process continues string the mixture with a constant speed of 1200rpm and maintains the temperature at 60°C for 2 hours. After the conducted process, the FFA amount is reduced to 1.2%.

Crude *calophyllum inophyllum* oil also have high amount of FFA which is equal to 28.96% after degumming process. Thus, same as crude *jatropha curcas* oil, *calophyllum inophyllum* oil was also initially treated with acid catalyzed esterification using hydrochloric acid (HCl) and methanol to reduce the FFA content. This pre-treatment process was done using 1% v/v of HCl and 25% v/v of methanol in oil at 60°C. Again, the process continues string the mixture with a constant speed of 1200rpm and maintain at 60°C for 2 hours. The process reduced the FFA content from 28.96% to 2%.

Alkaline catalyzed transesterification process

The optimum conversion yield of palm oil is 90% by using 20% v/v of methanol and 0.5% w/v of KOH at 55°C for 1 hour. On top of that, the amount of glycerine produced during the transesterification process is around 9%.

However, *jatropha curcas* oil managed to achieve a conversion yield of 87% in the presence of 20% v/v of methanol and 0.5% w/v of KOH at 55°C for 2 hour process. Besides, 10% of glycerine is produced during the transesterification process as by-product.

Lastly, the transesterification reaction for *calophyllum inophyllum* oil was conducted by using 20% v/v of methanol and 0.5% w/v of KOH at 55°C for 2 hours. The final biodiesel obtained from *calophyllum inophyllum* oil is 85% and 5% of glycerine is collected as by-product during the process.

Biodiesel properties of palm, *jatropha curcas* and *calophyllum inophyllum*

The obtained biodiesel from the palm, *jatropha curcas* and *calophyllum inophyllum* are shown in Figure 4. Table 5 summarized the important physiochemical properties results of biodiesel produced. In this section, the physiochemical properties of produced biodiesel from these three fuels are discussed. Those reported results are compared with ASTM D6571 and EN 14214 biodiesel standards. All specified properties obtained from palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel are in acceptable ranges according to ASTM D 6571 and EN 14214 standards.

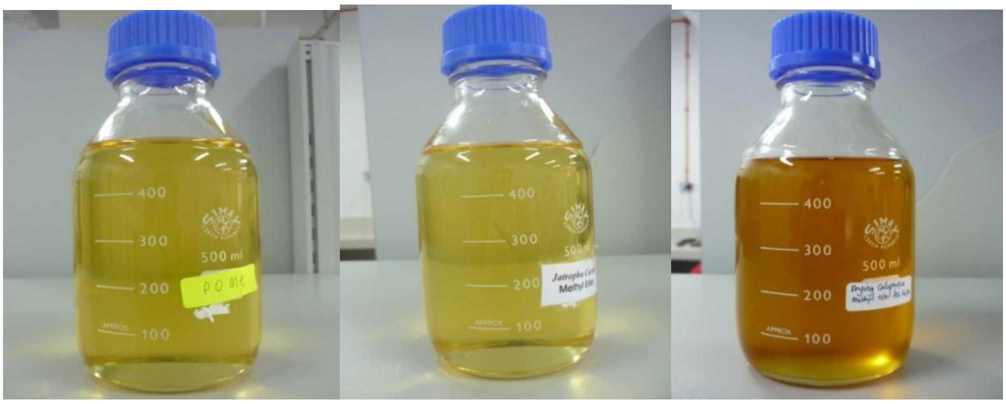

Figure 4. Palm (left), *jatropha curcas* (centre) and *calophyllum inophyllum* biodiesel (right)

Table 5. Physiochemical properties of palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel (methyl ester) compare with ASTM and EN standard.

Fuel Properties	Palm biodiesel	*Jatropha curcas* biodiesel	*Calophyllum inophyllum* biodiesel	ASTM D6751	EN14214
Density (kg/m^3)	885.4	868.9	872.3	-[a]	860-900
Viscosity at 40°C (cSt)	4.0	4.66	2.85	1.9–6.0	3.5-5.0
Calorific value (MJ/kg)	35.0	38.5	39.3	-[a]	-[a]
Acid (Neutralization) value (mg KOH/g)	0.28	0.41	0.33	Max.0.50	Max 0.50
Flash point (°C)	162.5	158.3	141.0	Min 130	Min 101
Cloud point (°C)	11.7	9.8	10.4	-3-12	-[a]
Pour point (°C)	9.6	8.7	6.0	-15-10	-[a]
Water content (mg/kg)	198	161	133	-[a]	Max 500
Copper strip corrosion (50°C; 3 hrs)	1a	1a	1a	Max No. 3	Class 1

[a]Not specified

Life cycle cost

Life cycle cost analysis is used to estimate the biodiesel production cost over a lifetime of 20 years. Life cycle cost model provides good assessment for long term cost effectiveness of a plant or project to build a sound business case for action. Life cycle cost is calculated for a typical 50 ktons biodiesel plant located in Malaysia. The life cycle costs of biodiesel production from palm, *jatropha curcas* and *calophyllum inophyllum* oil are calculated based on Eq. 1. Life cycle cost of biodiesel production from palm, *jatropha curcas* and *calophyllum inophyllum* are illustrated in Figure 5. The life cycle cost is shown in the present value by considering 8% discount rate. The results revealed that palm biodiesel production cost is higher compare to *jatropha curcas* and *calophyllum inophyllum* biodiesel. However, the life cycle cost of *jatropha curcas* and *calophyllum inophyllum* biodiesel production are almost similar.

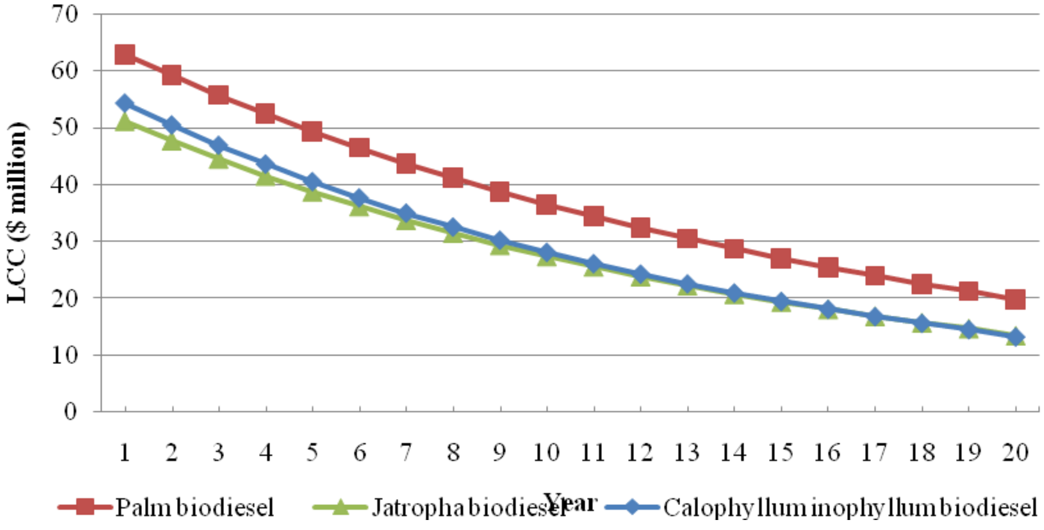

Figure . Life cycle cost of biodiesel production over 20 years life time.

Figure 6 illustrates the comparison of life cycle cost for palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel production and the distribution of biodiesel production life cycle cost. The largest share of life cycle cost of biodiesel production belongs to the feedstock price which is $643.3, $438.6 and $470 million for palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel respectively, followed by operating, capital and capital cost. Besides, the sale of by-products glycerine is a source of income which contributes

$16.4, $17.3 and $13.5 million over the life of the project for palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel respectively.

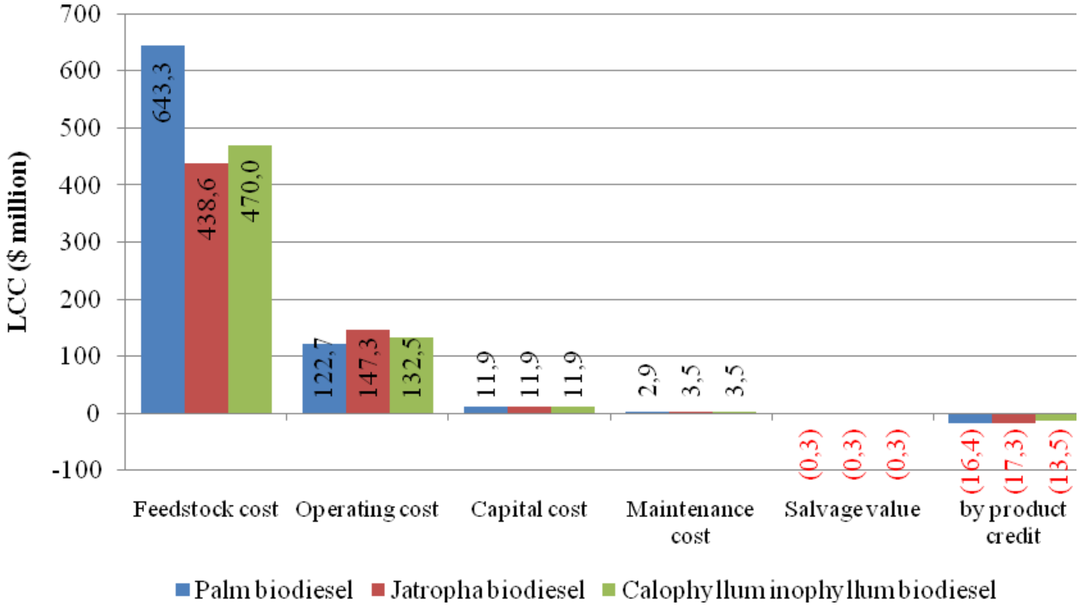

Figure 6. Comparison of life cycle cost for palm, *jatropha curcas* and *calophyllum inophyllum* production.

The summary of life cycle cost and payback period for biodiesel production are presented in Table 6. It is shown that the total life cycle costs of biodiesel production are $780, $601 and $617 million for palm, *jatropha curcas* and *calophyllum inophyllum* respectively without taking into account the glycerine credit. The largest economic factor for the life cycle cost of biodiesel production is feedstock which is about 82%, 73% and 76% of total life cycle cost for palm, *jatropha curcas* and *calophyllum inophyllum* oil respectively. Palm oil biodiesel accounted the highest percentage of feedstock cost among other biodiesel productions due to the high price of crude palm oil. Moreover, the other important costs are operating costs such as labour cost, utilities, laboratory, administration cost as well as other raw materials and chemical used in the process. The total operating cost is ranged from 16% to 24% of the total life cycle cost.

The sales of by-products are a source of income and it contains around 2% of the biodiesel production cost. On top of that, the total biodiesel production life cycle cost decreased to $764, $583 and $604 million by taking into account the glycerine credit for palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel respectively. On the other hand, the unit production cost of palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel are calculated to be $0.672/litre, $0.503/litre and $0.525/litre respectively.

Payback period as an effective tool is used to determine the required time to recover the investment. This is very important for financial management to monitor the recovery time of the project. The payback period for 50 ktons of palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel production plant was found to be 3.52, 1.90 and 1.98 years respectively. Being less than one third of the 20 year project life, this result indicates that the project is economically feasible.

Table 6. Summary of life cycle cost and payback period for biodiesel production

	Palm biodiesel		*Jatropha curcas* biodiesel		*calophyllum inophyllum* biodiesel	
	$	%	$	%	$	%
Capital cost	11,882,425	1.52%	11,882,425	1.98%	11,882,425	1.92%
Operating cost	122,726,843	15.72%	147,272,211	24.51%	132,544,990	21.46%
Maintenance cost	2,916,585	0.37%	3,499,902	0.58%	3,499,902	0.57%
Feedstock cost	643,348,614	82.42%	438,583,834	72.98%	470,045,283	76.09%
Salvage value	260,841	0.03%	260,841	0.04%	260,841	0.04%
by product credit	16,363,579	2.10%	17,326,142	2.88%	13,542,272	2.19%
LCC (w/o by product credit)	780,613,626		600,977,532		617,711,759	
Total life cycle cost	764,250,047		583,651,389		604,169,487	
Production unit cost ($/litre)	0.672		0.503		0.525	
Payback period (year)	3.52		1.90		1.98	

Sensitivity analysis

Sensitivity analysis investigates the impact of input parameter variation on the model's conclusions. Figure 7-9 shows the results of sensitivity analysis of palm, *jatropha* and *calophyllum inophyllum* biodiesel production for five input variables respectively. The legends on the left of the figure give the variation in the sensitivity variable from favourable, to planned and to unfavourable. As expected, variation in the price of crude oil represents the dominant impact on life cycle cost. For instance, CPO price of $700/ton reduces the life cycle cost to $570 million compared to more than $950 million of life cycle cost for CPO price of $1300/ton.. Furthermore, the present value discount rate also causes a huge impact on the life cycle cost of palm biodiesel production. Variation in oil conversion yield and operating costs have the lower impact of the on-going costs, but together can offset significant variation in biodiesel production cost. Continual improvement in the biodiesel conversion processes and greater operating efficiency can lead to a significant reduction in overall biodiesel production costs.

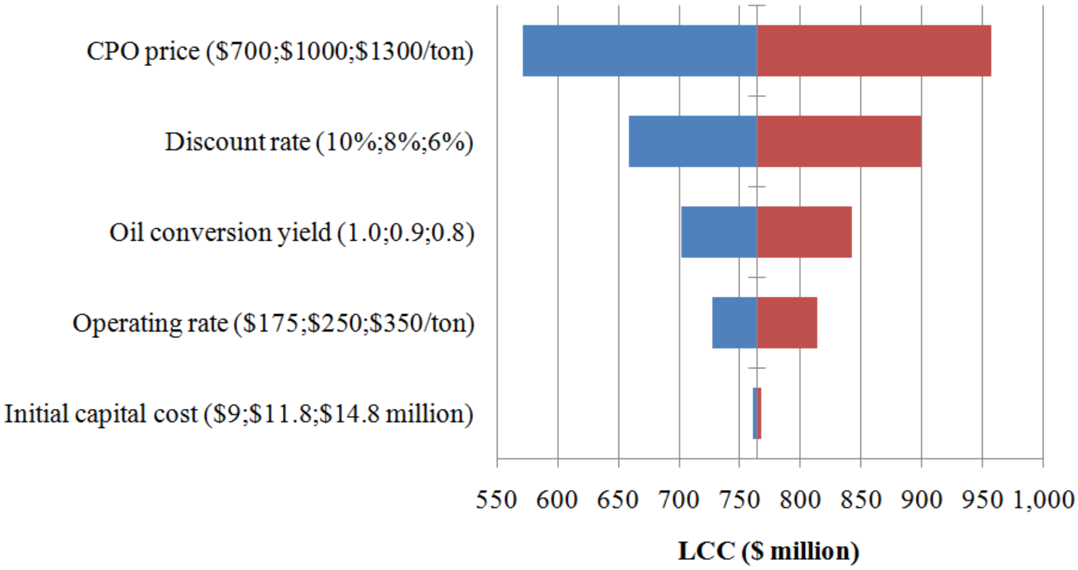

Figure 7. Sensitivity analysis of life cycle cost for palm biodiesel production.

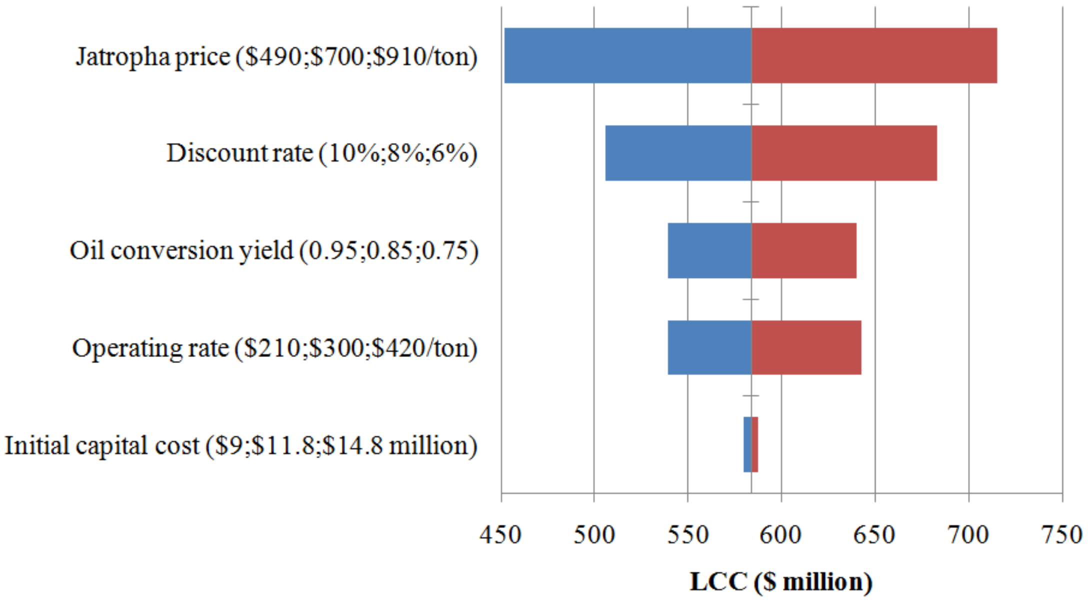

Figure 8: Sensitivity analysis of life cycle cost for *jatropha curcas* biodiesel production.

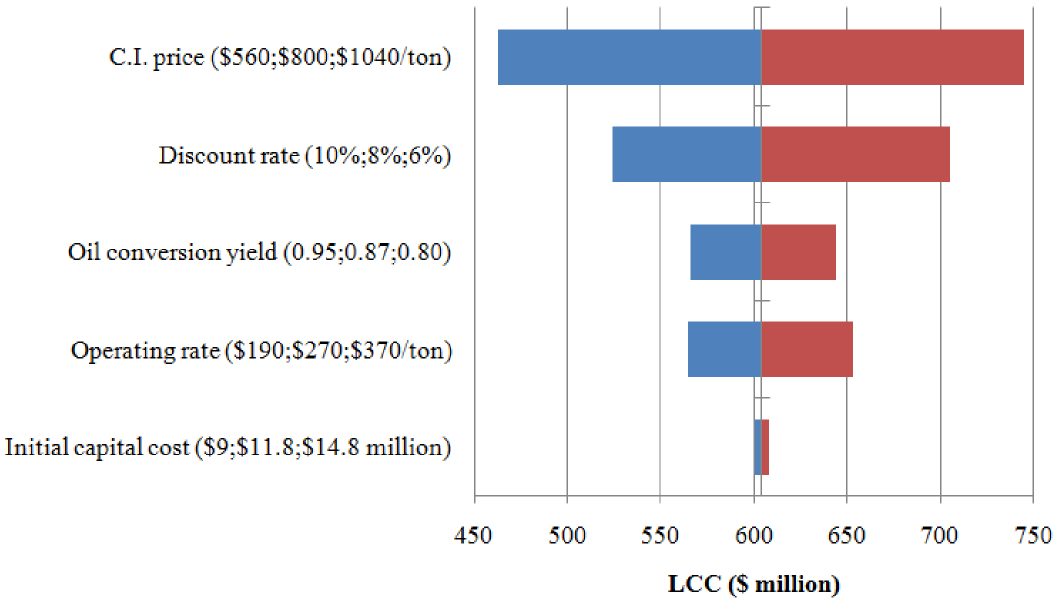

Figure 9. Sensitivity analysis of life cycle cost for *calophyllum inophyllum* biodiesel production.

Taxation and subsidy scenarios at varying feedstock price

Taxation and subsidy scenarios based on final biodiesel cost as a function of crude feedstock price are discussed here. There are four taxation and subsidies scenarios considered which are tax exempted, 15% of taxes, subsidy of $0.10/litre and $0.18/litre for biodiesel. Figure 10 shows the taxation and subsidy scenarios of palm oil biodiesel at a function of CPO price. As shown in the figure, the biodiesel is competitive with fossil diesel fuel when the CPO price below $0.6/kg or $600/ton with tax exemption. However, when the price of CPO surges up to $950/ton, the biodiesel price becomes higher than the fossil diesel although $0.18/litre of subsidy is provided.

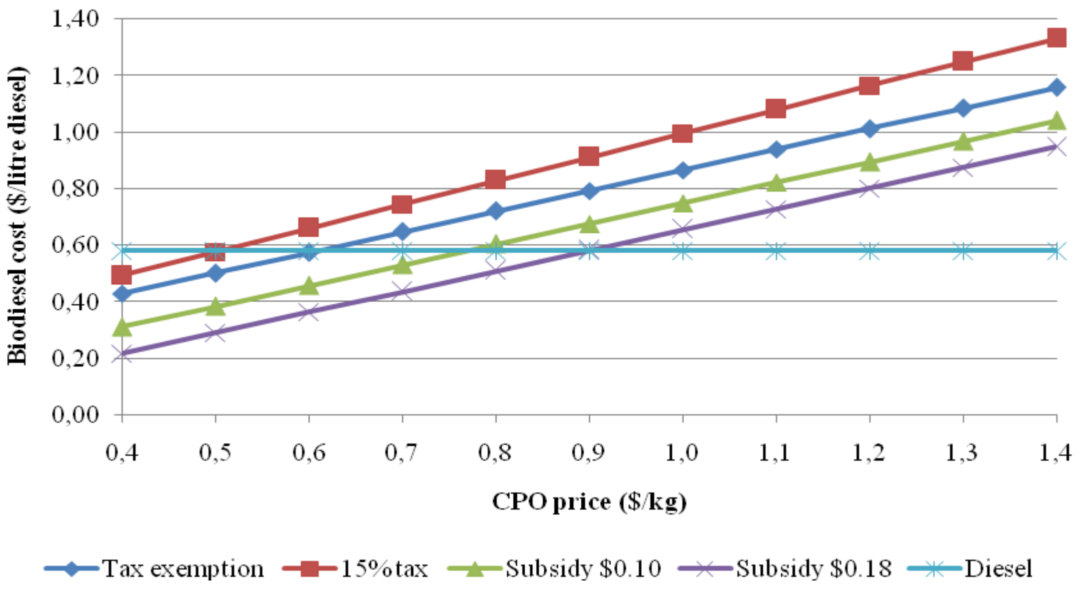

Figure 10. Taxation and subsidy scenarios of palm biodiesel on CPO price.

Taxation and subsidy scenarios of *jatropha curcas* biodiesel at varying CJO price are illustrated in Fig. 11. The biodiesel is competitive with diesel fuel when the CJO price is below $0.7/kg with tax exemption. On the other hand, with subsidy for biodiesel of $0.10 and $0.18/litre, the CJO price could reach $0.83/kg and $0.97/kg respectively in order to preserve the competitiveness with diesel fuel. Apart from that, when the price of CJO is above $970/ton, the biodiesel price is higher than fossil diesel although $0.18/litre of subsidy is provided.

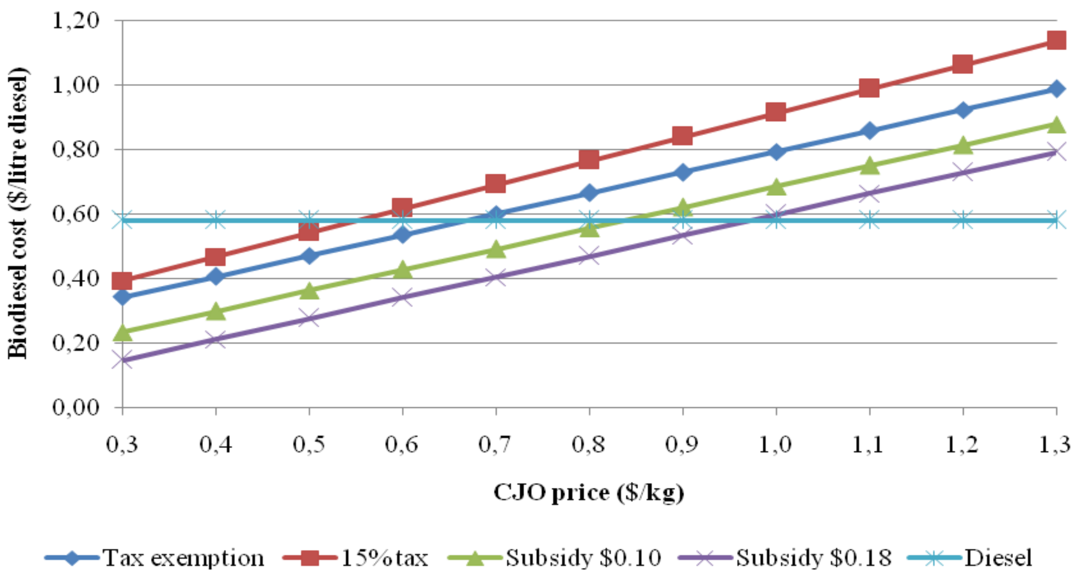

Figure 11. Taxation and subsidy scenarios of *jatropha curcas* biodiesel on CJO price.

Figure 12 shows the taxation and subsidy scenarios of *calophyllum inophyllum* oil based on the biodiesel cost as a function of CBO price. When the price of CBO is below $750/ton and without giving any direct subsidy, biodiesel fuel is competitive with diesel. However, when the price of CBO surges up to $1.07/kg, the biodiesel price becomes higher than fossil diesel although $0.18/litre of subsidy is provided. On top of that, when the CBO price reaches $1.0/kg, subsidy should be provided in order to preserve the competitiveness of biodiesel with fossil diesel.

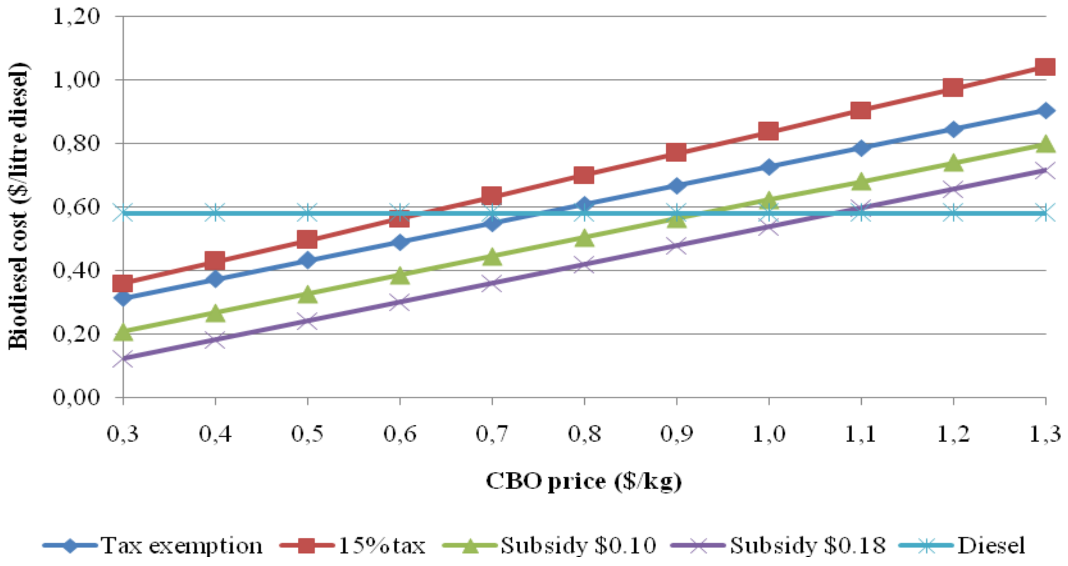

Figure 12. Taxation and subsidy scenarios of *calophyllum inophyllum* biodiesel on CBO price.

Economic impact: biodiesel breakeven cost

Biodiesel breakeven cost is at a point in which price of the biodiesel is economically competitive with the fossil diesel. Biodiesel breakeven cost is calculated based on the comparison between the biodiesel production costs at different crude fossil oil price. The different energy content of biodiesel and diesel fuel is taken into account. Thus, the cost of biodiesel production is converted to diesel fuel by considering the substitution ratio. The calculated breakeven price is based on no subsidy assumption for both fuels. The breakeven price for biodiesel at different petroleum oil and crude oil price are presented in Figure 13-15 for palm, jatropha and calophyllum inophyllum respectively. The upper part area of the line in the figure presents the subsidy needed for replacement of diesel fuel with palm biodiesel fuel. Whereas, the lower part of the line area is the potential saving generated by the substitution.

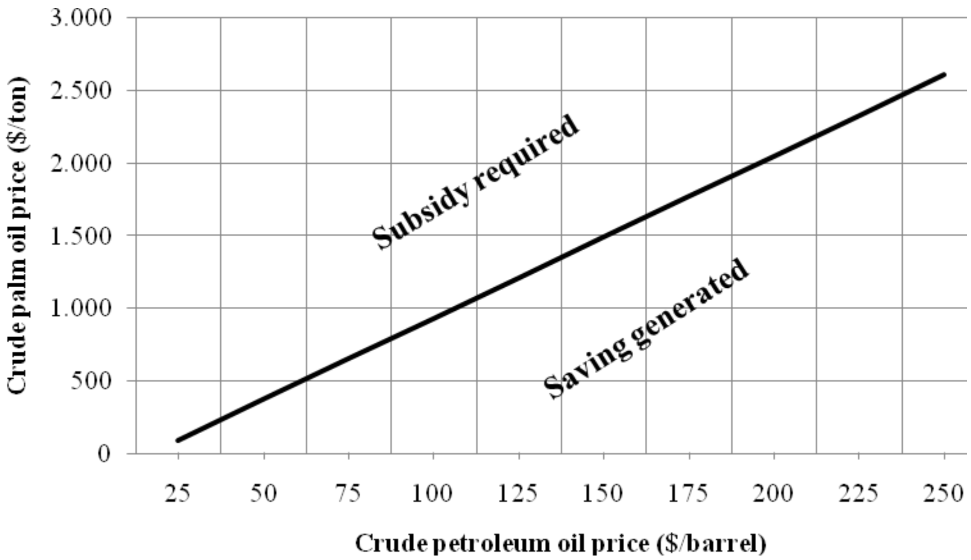

Figure 13: Breakeven price for palm biodiesel production at different petroleum and CPO prices.

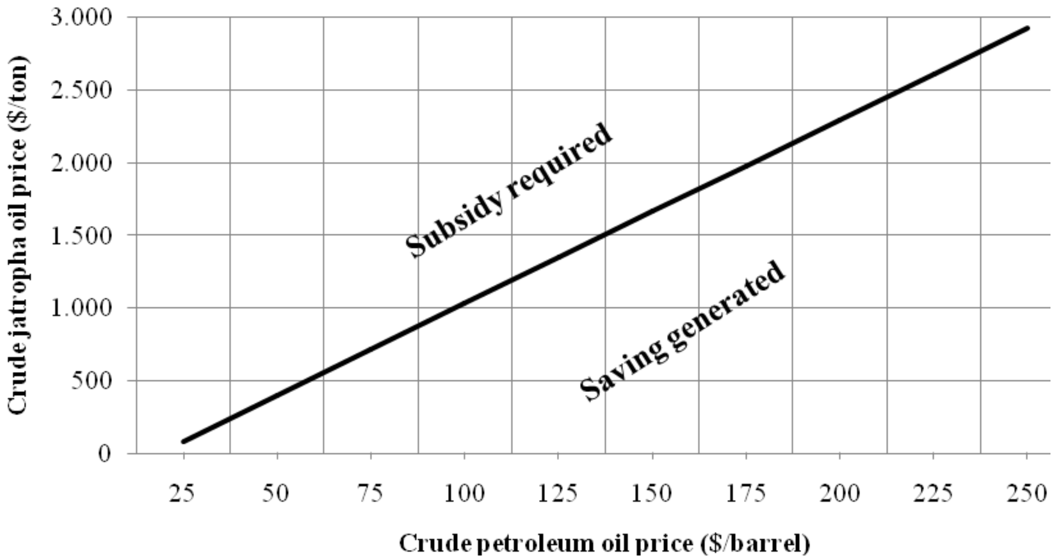

Figure 14: Breakeven price for *jatropha curcas* biodiesel production at different petroleum and CJO prices.

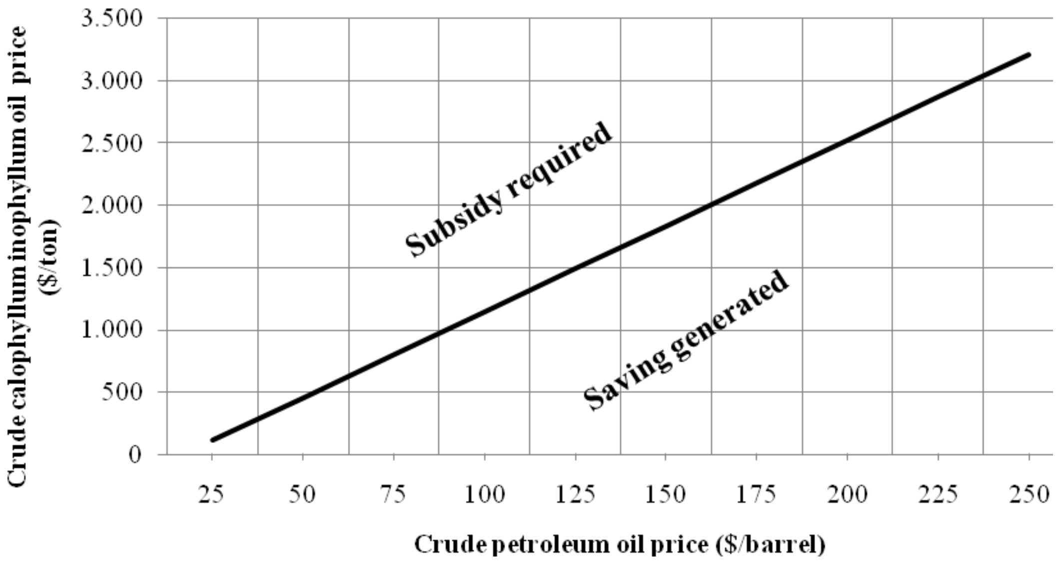

Figure 15: Breakeven price for *calophyllum inophyllum* biodiesel production at different petroleum and CBO prices.

Conclusions

Biodiesel fuel is being recognized as a solution for diesel fuel in the transportation sector which brings many benefits to environment. Laboratory experiments are carried out to study the biodiesel production process and biodiesel fuel characteristics. Besides the technical factors, economic impacts of biodiesel production also play an important role in the development of this industry. Thus, life cycle cost model and payback period of biodiesel production were developed and it is flexible as it can be modified. It has been found that the total life cycle cost of palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel is $764, $583 and $604 million respectively by taking into account the glycerine credit. Payback period for 50 ktons of palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel production plant was found to be 3.52, 1.90 and 1.98 years respectively, the results indicated that biodiesel production plants are economically feasible. As a final note, biodiesel policies and subsidies should be urgently reviewed in order to preserve the goal of energy saving, emissions reduction and economic impact.

Acknowledgements

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