TECHNO – ECONOMIC ANALYSIS OF JATROPHA CURCAS BIODIESEL PRODUCTION IN MALAYSIA

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DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF MASTER OF MECHANICAL ENGINEERING

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ABSTRACT

The reduction of the high demand for crude oil is solved by increasing the production of biodiesel as the alternative fuel and at the same time can lessen the emissions of greenhouse gases. Most of the developing countries could not utilize and produce biodiesel at full potential due to some factors such as technical constraints, feedstock price, production cost, fossil fuel and taxation policy, depending on countries. This project paper evaluates the matters above by commencing a techno-economic and sensitivity analysis of biodiesel production in Malaysia by using feedstock from Jatropha *curcas*. The projected operating period is taken for 10 years starting from 2012 to 2022. The advantages of using non-edible Jatropha *curcas* as feedstock for biodiesel are it is drought-restraint plant, ability to grow anywhere, valuable properties of seeds, and known to have better cold properties compared to palm oil. The model of life cycle as well as the sensitivity analysis is taken as 50 ktons of biodiesel plant. Hence, the biodiesel production plant life cycle cost is estimated to be $315 million which yields a Jatropha biodiesel unit cost of $0.661/l over the project lifetime. The payback period was found to be 2.69 years, which is less than one third of the project lifetime. Jatropha biodiesel has proven to be feasible economically, recommended that in order to process and produce Jatropha biodiesel, the oil used should be in large quantities as the production cost to produce it is costly. The result of the analysis done in this paper would be able to provide future potential of Jatropha Curcas for biodiesel production in Malaysia.

ABSTRAK

Pengurangan permintaan yang tinggi bagi minyak mentah diselesaikan dengan meningkatkan pengeluaran biodiesel sebagai bahan api alternatif dan pada masa yang sama boleh mengurangkan pelepasan gas rumah hijau. Kebanyakan negara-negara membangun tidak dapat menggunakan dan menghasilkan biodiesel pada potensi penuh disebabkan oleh beberapa faktor seperti kekangan teknikal, harga bahan mentah, kos pengeluaran, bahan api fosil dan dasar cukai, bergantung kepada negara. Kertas projek ini menilai perkara-perkara di atas dengan memulakan analisis tekno-ekonomi dan sensitiviti pengeluaran biodiesel di Malaysia dengan menggunakan bahan mentah dari Jatropha *Curcas*. Operasi yang diunjurkan tempoh yang diambil selama 10 tahun bermula 2012-2022. Kelebihan menggunakan Jatropha *curcas* yang tidak boleh dimakan sebagai bahan mentah untuk biodiesel ia adalah tumbuhan kemarau-sekatan, keupayaan untuk tumbuh di mana-mana, benih yang mempunyai sifat-sifat yang berharga, dan dikenali lebih baik untuk mempunyai sifat sejuk berbanding minyak sawit. Model kitaran hidup serta analisis sensitiviti yang diambil sebagai 50 ktons loji biodiesel. Oleh itu, pengeluaran biodiesel tumbuhan kos kitar hayat dianggarkan $315 juta yang menghasilkan satu Jatropha biodiesel unit kos $0.661/l sepanjang hayat projek. Tempoh bayaran balik didapati 2.69 tahun, yang kurang daripada satu pertiga daripada hayat projek. Jatropha biodiesel telah terbukti dilaksanakan dari segi ekonomi, disyorkan bahawa untuk memproses dan menghasilkan Jatropha biodiesel, minyak yang digunakan hendaklah dalam kuantiti yang besar kerana kos pengeluaran untuk menghasilkan ia adalah mahal. Hasil daripada analisis yang dilakukan dalam kerja ini akan dapat menyediakan potensi masa depan Jatropha Curcas untuk pengeluaran biodiesel di Malaysia.

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LIST OF SYMBOLS AND ABBREVIATIONS

BP	by product credit ($)
CC	capital cost ($)
CE	biodiesel conversion efficiency
CPW	compound present worth factor
CJO	crude jatropha oil
d	depreciation ratio (%)
FC	feedstock cost ($)
FP	feedstock price ($/ton)
FU	feedstock consumption (ton)
GCF	glycerol conversion factor from feedstock oil
GP	glycerol price ($/kg)
i	year
LCC	life cycle cost ($)
MC	maintenance cost ($)
MR	maintenance ration (%)
n	project life time (year)
OC	operating cost ($)
OR	operating rate ($/ton)
PC	annual biodiesel production capacity (ton/year)
PP	payback period
PWF	present worth factor
RC	replacement cost
r	interest rate (%)
SV	salvage value ($)
TAX	annual total tax ($/year)
TBS	annual total biodiesel sales ($/year)

TPC	annual total production cost ($/year)
$	monetary unit is in US dollar
l	litre
ktons	kilo tons
kg	kilogram
MJ	mega joules
CO_2	carbon dioxide
NO_x	nitrogen dioxide
cSt	centistokes

CHAPTER 1: INTRODUCTION

1.1. Background

Fossil fuels are the most important source of energy the world has today. Without fossil fuels, energy generation would not be produced to give the community heating, transportation, electricity and many more. Petroleum, natural gas and coal are the three main important basic fossil fuels. These fossil fuels were produced due to fossilization of plants and animals that lived hundreds of years ago, in a form of concentrated biomass. They are concentrated organic compounds that can be found in the Earth's crust. Those plants and animals will decay and they will go back into their most basic forms; Coal is carbon in its genuine form, and petroleum and natural gas are hydrocarbons formed during the process of decaying.

It is aware and notified by all over the world that the Earth's fossil fuels are depleting as year goes by. However, the demands keep on increasing as more and more equipments, instruments and machines utilize fossil fuels to generate. The Energy Information Administration (EIA) states that the total primary energy consumption in Malaysia in 2008 was 2.612 Quadrillion Btu and has increased to 2.693 Quadrillion Btu in 2009. That is about 3.1% growth over a year. Compared to year 1990 to 2008, the growth was about 7.2% (Ong et. al., 2011). The total primary energy production in Malaysia was 3.798 Quadrillion Btu in 2008 and decreased in 2009 to 3.707 Quadrillion Btu. Other than depleting fossil fuels problem, some negative impacts over the usage of these fossil fuels have arises and worries not only the scientists but the community as well. The most common negative impacts faced nowadays are global climate by emissions of greenhouse gases, and local air quality by emissions of hydrocarbons, NO_x. According to the Energy Information Administration (EIA), the total consumption of fossil fuel in Malaysia in 2009 was about 179.13 million metric tons of CO_2 released and has increased in 2010 to 181.93 million metric tons of CO_2 released.

Thus, with the worrisome negative impacts due to the usage of fossil fuels for energy generation, scientists and researchers all around the world are working hard to find alternative renewable energy sources that are clean, reliable, as well as economically reasonable. Out of all the alternatives, biodiesel is found to be much cleaner renewable fuel and is considered as the best contender for diesel fuel replacement out of all because of its capability to be used in any compression ignition engine with needless to modify the engine (Apostolakou et. al., 2009).

There are a lot of advantages of biodiesel that makes it competitive with fossil diesel. One of the main advantage of biodiesel is it is produced from renewable resources that can be gained domestically. An example of renewable resource is vegetables oil, which can be obtained or made easily. The next advantage is it produces less carbon monoxide, particulates as well as sulfur dioxide emissions, which is the main concern of negative impact brought by fossil diesel. Another advantage that can reduce the greenhouse effect caused by fossil diesel is that biodiesel produces 50% less carbon dioxide. Some other advantages of biodiesel are it is biodegradable, non-toxic and safer to handle (Apostolakou et. al., 2009). In fact, biodiesel has rise to the next level as it is also claimed to enhance economic development while reclaiming marginal and degraded lands in arid regions, without competing with food production or depleting natural carbon stocks as well as ecosystem services (Achten et. al., 2010).

There are also some disadvantages of biodiesel which has yet to be solved. The main disadvantage of biodiesel is its high price due to its expensive production cost. The cost to produce biodiesel to make it compatible with equipments, vehicles or instruments which has been using fossil diesel before, is known to be expensive (Apostolakou et. al., 2009).

1.2 Problem Statement

The depleting of fossil diesels has garnered much attention to the world problem. Scientists and researchers have started to find alternative solution to this problem. One of the suitable alternatives to replace fossil diesels is renewable energy. Well known renewable energy that can replace fossil diesel is biodiesel. Biodiesel is derived from biomass. Biomass is organic matter which is produced by plants or animals. Biodiesels can be in any type; solid, gaseous or liquid that can be derived from biomass (Uriarte, 2010). The focus in this work is assessing the production cost for biodiesel of liquid type as alternative fuel to replace fossil diesel. Some of biodiesels are produced mostly from plants that can be compatible to replace fossil diesel in equipments, vehicles, and machines. Some biodiesels produced from plants have already established in the market. Some biodiesels are made from palm, rapeseed, soybean, corn, cottonseed, sesame, safflower, sunflower, jatropha and many more. Producing biodiesel may be costly due to the lack of resources, edible plant competition, or probably due to manpower. The main concern from the investors would probably be the payback period of the investments on biodiesels.

1.3 Objective of study

The objective of this study is to assess the life cycle costs as well as the payback period for biodiesel production in Malaysia. The sensitivity analysis of the biodiesel production also will be evaluated in this study to estimate different type of performances compared to the main assumption on which the estimations are based. This study also includes analyzing the taxation and subsidy scenarios for the current biodiesel production cost.

1.4 Scope of study

The scope of this study focuses on evaluating the life cycle cost and sensitivity analysis of biodiesel production cost specifically using Jatropha *curcas L.* plant. It is still a new renewable energy in Malaysia to replace fossil diesel. Nonetheless, Jatropha biodiesel has high potential to replace fossil diesel as well as palm biodiesel, given that the price of palm biodiesel has risen due to its high demand.

CHAPTER 2: LITERATURE REVIEW

The awareness in bio-fuels matters has become a major concern globally for the past years. Most countries in the world are struggling to find the replacement for fossil fuels that are depleting rapidly from years to years. Furthermore, air pollution has becoming the most critical environmental problems due to a large amount of emission majorly CO_2 and NO_x released to the environment mostly by vehicles. This shows that the consumption of energy in all aspects has been consistently increasing and rising in almost all of the country in the world (Jain & Sharma, 2010). Previously, during petroleum deficiency, alternative fuels such as vegetable oils and its derivatives have been recommended as a replacement fuels for petroleum diesel. The significant of the replacement fuels are that it is technically feasible, economically competitive, environmentally acceptable and readily available. The most important benefits of using vegetable oils or also known as bio-diesel fuels are such as: (1) lower dependence on crude oil, (2) renewable fuel, (3) favorable energy balance, (4) reduction in greenhouse gas emission, (5) lower harmful emission, (6) biodegradable and non-toxic, (7) use of agricultural extra and (8) safer handling (higher flash point than conventional diesel fuel) (Abdullah et. al., 2009).

In Malaysia, the total consumption of crude oil in year 2012 was 539 thousands of barrels per day compared to in year 2011 were 605 thousand barrels per day, which is about 3.3% increment from year 2008 to 2009. The net export and import of the crude oil increased from year 2011 to 2012 by 79% while the total demands in Malaysia; in fact all around the world is increasing year by year (EIA, International Energy Statistics, 2013).

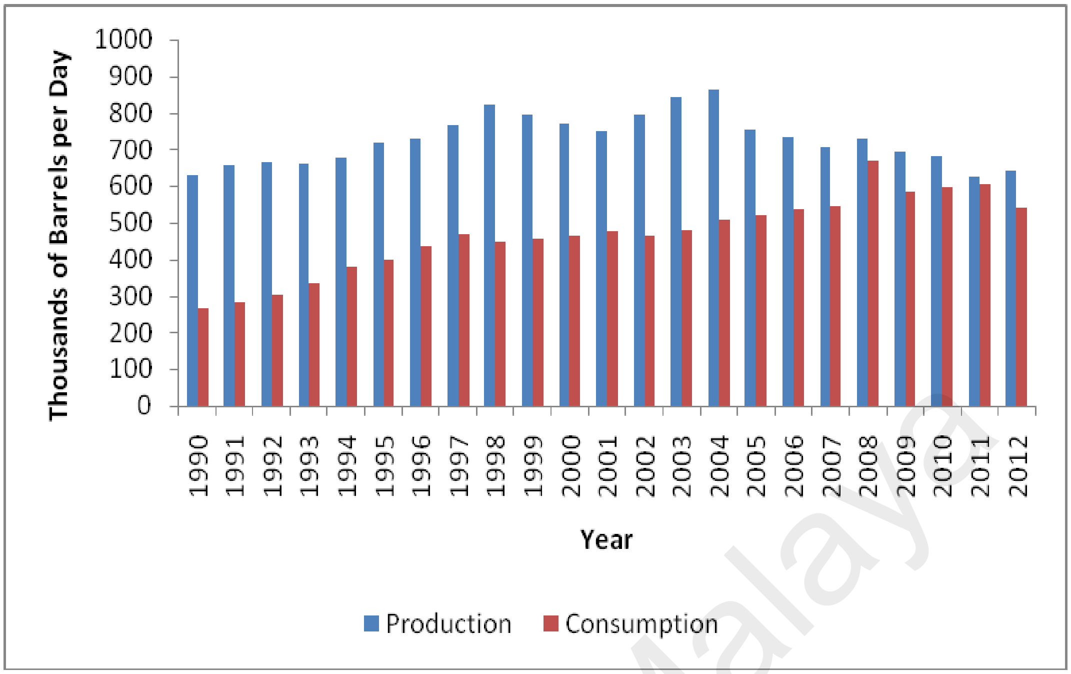


Figure 2.1: Total Oil Production and Consumption in Malaysia (EIA).

2.1. Oil as resources of Biodiesel

With the increasing demand of the fossil fuel and the depletion of fossil fuel, this leads to the rapid increase of crude oil price. Due to the exhaustion of the fossil fuel and the increment of the price concurrently, the exploration of renewable energy, such as in this case, biodiesel has become the most important aspects to replace the fossil fuel to prepare the world before the fossil fuel comes to an end (Abdullah et. al., 2009). Biodiesel is another option of fuel which is mainly produced by renewable vegetable oils, animal fats or recycled cooking oils by transesterification reaction. Currently, Europe and USA are the largest commercialized biodiesel production among other countries in order to reduce air pollution and greenhouse effect (Lu et. al., 2009). However, when talking about biodiesels, they are identified as highly controversial as their production is important in terms of economic (e.g, subsidies and protectionism), social (e.g, food security) and environmental risks (e.g., loss of biodiversity and water recharge, negative carbon balance) (Atchen et. al., 2010).

Choosing alternative fuels, which will replace fossil fuel, should be easy to obtain at a low cost, environmentally friendly and able to fulfill the energy security need without affecting the engine's operational performance (Agarwal, 2007). The source of biodiesel production is normally selected according to the availability of the source in every region or country. Currently, in Malaysia, the alternative fuel largely produced and commercialized is palm oil. In 2008, Malaysia produced 17.6 million tons of palm oil that put Malaysia the leading producer of palm oil in the world. Malaysia is also taking practical steps in maneuvering the development of biofuel throughout the country (Abdullah et. al., 2009).

2.1.1. Biodiesel

The invention of vegetable oil for fuel comes from a man named Rudolph Diesel, who was also the inventor of diesel engine. He experimented with fuels using materials such as powder coal, peanut oil and many more (EIA, Energy Information Administration). His first biodiesel using vegetable oil was demonstrated at the World Exhibition at Paris in 1900, whereby his compression ignition (CI) diesel engine was developed using peanut oil as a fuel. Unfortunately, the research and development pursuits on vegetable oil were not seriously continued due to the large amount of supply of diesel and vegetable oil fuel were more expensive than diesel (Ong et. al., 2011). Then, when the issue of depleting fossil fuel became the most concerned world issue, biodiesel has gained much interest among the researchers to substitute petroleum fuel to overcome the problems of depleting nature resources as well as the negative environmental issues.

As an alternative for replacing fossil fuels, biodiesel has gain a lot of attention and open the whole world's eye in order to save Earth damaged from pollution and excessive emissions. Biodiesel is defined as the fatty acid methylester or mono-alkyl esters which are derived from vegetable (plant) oils or animal fats as well as other biomass-derived oils or alcohols of lower molecular weight in the presence of catalyst that meet certain quality of specifications (Atadashi et. al., 2010). Biodiesel is considered as the best alternative renewable energy diesel fuels for diesel engines (Demirbas, 2007). The chemical conversion of the vegetable oils to mono-alkyl esters can be accomplished by going through a process known as transesterification.

Biodiesel offers a lot of benefits and priorities such as its sustainability, reduction of greenhouse gas emissions, its development towards regional, social structure as well as agriculture and security of supply (Demirbas, 2007).

2.1.2. Vegetable oil as diesel substitute

Vegetable oil is known as triglycerides in scientific term. It has become one of the high potentially renewable feedstock for biodiesel production due to its environmental benefits. It is also known to be a promising alternative to replace diesel fuel because of being renewable with energy content that is similar to diesel fuel subsequently undergoing some chemical modifications (May et. al., 2011). Vegetable oil contains fatty acids, free fatty acids, phospholipids, phosphatides, carotenes, tocopherols, sulphur compound and water. The fatty acids usually found in vegetable oil such as stearic, palmitic, oleic, linoleic and linolenic (Ong et. al., 2011). Table 2.1 shows the summary of the fatty acid composition of some common vegetable oil. It is known that more than 95% of biodiesel production feedstock comes from edible oils due to the similar properties to petroleum-based diesel and have a great potential to substitute petroleum–based diesel in a long term (May et. al., 2011).

Table 2.1: Fatty acid composition for different vegetable oils

Fatty acid	**Jatropha oil**	**Pongamia (Karanja oil)**	**Sunflower oil**	**Soybean oil**	**Palm oil**
Lauric (C_{12}/0)	-	-	0.5	-	-
Myristic (C_{14}/0)	-	-	0.2	0.1	-
Palmitic (C_{16}/0)	14.2	9.8	4.8	11.0	40.3
Palmitoleic (C_{16}/1)	1.4	-	0.8	0.1	-
Stearic (C_{18}/0)	6.9	6.2	5.7	4.0	3.1
Oleic (C_{18}/1)	43.1	72.2	20.6	23.4	43.4
Linoleic (C_{18}/2)	34.4	11.8	66.2	53.2	13.2
Linolenic (C_{18}/3)	-	-	0.8	7.8	-
Arachidic (C_{20}/0)	-	-	0.4	0.3	-
Behenic (C_{22}/0)	-	-	-	0.1	-
Saturates (%)	21.1	16.0	11.6	15.5	43.4
Unsaturates (%)	78.9	84.0	88.4	84.5	56.6

Source: May et. al., 2011.

2.1.3. Fuel properties of vegetable oils

The fuel properties of vegetable oils show that the kinematic viscosity of it differs in the range of 30–40 cSt at 38°C and can be seen in Table 2.2. These oils high viscosity is due to their large molecular weight in the range of 600–900, that is three times higher than diesel fuel. The vegetable oil has a very high flash point that is above 200°C, that makes the higher heating value of these oils are in the range of 39-40 MJ/kg which is lower than diesel fuel approximately 45 MJ/kg. There is chemical bound oxygen presence in the vegetable oil that makes their heating values lower by 13%. The range of cetane number are from 32-40, while the iodine value ranges from 0 to 200 depends on unsaturation. Whereas, the cloud and pour points are known to be higher than diesel. It is difficult to use vegetable oils directly in the engine due to their viscosity is almost 20-25 times higher (40-50 cSt) than diesel, which will cause the piston ring sticking, gum formation and fuel automization problem. This is why the vegetable oils need to go for modification in order to reduce the viscosity. It is also known that vegetable oils have higher flash point as well as lower calorific value compared to diesel (Jain & Sharma, 2010).

Table 2.2: Fuel properties of vegetable oil.

Vegetable oils	**Cetane number**	**Heating values (MJ/kg)**	**Cloud point (°C)**	**Pour point (°C)**	**Kinematic viscosity (cSt at 38°C)**	**Flash point**	**Specific gravity at 15°C**
Corn	37.6	39.5	-1.1	-40.0	34.9	277	0.9095
Cottonseed	41.8	39.5	1.7	-15.0	33.5	234	0.9148
Rapeseed	36.7	39.7	-3.9	-31.7	37.0	246	0.9115
Safflower	41.3	39.5	18.3	-6.7	31.3	260	0.9144
Sesame	40.2	39.3	-3.9	9.4	35.5	260	0.9133
Soybean	37.9	39.6	-3.9	-12.2	32.6	254	0.9138
Sunflower	37.1	39.6	7.2	-15.0	33.9	274	0.9161
Palm	42.0	39.5	31.0	-	39.6	267	0.9180
Jatropha	40-45	39-40	-	-	55 at 30°C	240	0.912
Diesel	40-55	42	-15 to -5	-33 to -15	1.3-4.1	60-80	0.82-0.86

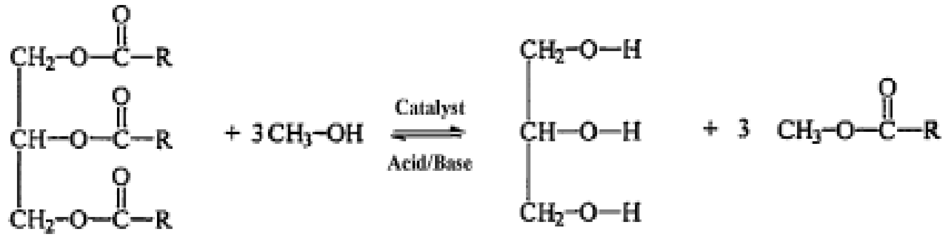
Source: Jain & Sharma, 2010.

2.1.4. Modification of vegetable oil

Vegetable oils are known as the best substitute as diesel fuel for diesel engines due to their high energy content. Nevertheless, using vegetable oils directly will cause various problems to the engine (May et. al., 2011). Their high viscosity which are about 10 times higher than diesel fuel will cause poor fuel automization, incomplete combustion, cocking of the fuel injectors and many more problems. These advantages, not only due to high viscosity of vegetable oils but also the usage of unsaturated vegetable oils, may cause damage to the engine but can be solved by modifying the biodiesel chemically to have the similar characteristic as diesel fuel (Schwab et. al., 1987; Barnwal & Sharma, 2005). Transesterification of the vegetable oil will reduce the viscosity of the oil to a range of 4-5 mm^2/s closer to that of diesel and therefore improves combustion (Sahoo et. al., 2009; Knothe, 2010). Thus, biodiesels or also known as fatty acid esters, are more efficient, clean as well as they are natural energy alternative to petroleum fuel (Balat, 2005).

2.1.5. Transesterification of vegetable oil

According to a research done by Houfang Lu et. al. (2009), in conventional processes, biodiesel is produced by the transesterification of vegetable oils with methanol in the existence of catalysts, such as alkalis (KOH, NaOH) or their equivalent alkoxides to speed up the reaction. Transesterification is the common method of converting vegetable oil into biodiesel (methyl esters), which can be used directly or as mix with diesel in a diesel engine (Jain & Sharma, 2010).



$$triglycerides(oil) + methanol \rightarrow glycerol + biodiesel(methylester)$$

Figure 2.2: Transesterification reaction.

2.2. Techno-economic analysis of vegetables oil

There are a lot of research and studies done by scientists and researchers on the techno-economic assessments of vegetables oil. The research and studies did for the economic analysis applied different and various feedstocks and the production methods used were different as well. Table 2.3 below summaries some of the economic analysis studies made for various feedstocks as well as different variables.

Table 2.3: Summary of techno-economic analysis of biodiesel production

Plant capacity tones/year	**Feedstock**	**Feedstock cost $/ton biodiesel**	**Glycerol credit $/ton biodiesel**	**Biodiesel cost $/l**	**Location**	**References**
1,000	Palm oil	588	200	2.30	India	Jegannathan et. al., 2011
36,000	Palm oil	358	33.5	0.37	Mexico	Lozada et. al., 2010
8,650	Castor oil	1156	44.1	1.56	Brazil	Santana et. al.,

						2010
8,000	Rapeseed oil	3042	2215	2.04	Denmark	Sotoft et. al., 2010
50,000	Rapeseed oil	1158	-	1.15	Greece	Apostolakou et. al., 2009
8,000	Soybean oil	779	380	0.78	USA	Yau YD et. al., 2008
36,000	Soybean oil	486	35.8	0.53	USA	Haas MJ et. al., 2006
7,260	Waste cooking oil	248	0	0.58	Japan	Sakai T et. al., 2009
8,000	Waste cooking oil	525	91.3	0.95	Canada	Zhang Y et. al., 2003
36,036	Waste cooking oil	905	67.5	0.98	Argentina	Marchetti JM et. al., 2008
36,036	Waste cooking oil	445	73.8	0.51	Argentina	Marchetti JM et. al., 2008

Source: Ong et. al., 2012.

2.3. Jatropha *curcas L.* as potential biodiesel

Even though palm oil is known as the major feedstock for biodiesel production in Malaysia, there is one specific plant that is also highly potential in producing biodiesel oil from its seeds. Jatropha is known to be an introduced and quite unknown plant in Malaysia not until in 2005 when it is known as a biofuel crop (MARDI, 2010). Jatropha *curcas L.*

(Euphorbiaceae) is a drought-resistant, photo-insensitive and perennial plant that has been drawing a lot of attention in most country in the world as an alternative source of biodiesel (Kochhar et. al., 2008) without struggling to compete with the production of food or without reducing natural carbon stocks and ecosystem services (Atchen et. al., 2010). Although it produces lesser amount of oil compared to palm oil, it has been testified that Jatropha has quite a number of advantages compared to palm oil. Jatropha is known to be able to grow on poor land (arid and marginal land), increasing the soil quality, requires only small amount of water, fertilizer and pesticides hence supplying several by-products from the production of Jatropha biodiesel for instance wood, glycerin and fertilizer (Prueksakorn et. al., 2010).

Figure 2.3: Jatropha plant and seed.

As a multipurpose tree, with a long history of agriculture in tropical and subtropical regions around the world, Jatropha seed contain viscous, non-edible oil that is used as a replacement for diesel from crude oil. Jatropha seeds contain 48% of oil where one liter of oil is produced from approximately 4 kg of Jatropha seeds and from this can be utilized for about 50 hours of lighting, while 350 mL of Jatropha oil can last up to 3 hours for cooking purposes. The seeds are known to be toxic because of the presence of cursive ingredients, but after doing some treatment to the seeds, it can be use as animal feed. The oil can also be use as high quantity soaps, manufactured candles and also cosmetic products since Jatropha plant is an environmental friendly and save to use. Jatropha can also be used as treatment to skin disease for instance eczema, acne, psoriasis and also rashes (Kochhar et.al., 2008).

Despite all the useful usage and properties of Jatropha plants, studies on agriculture, development and propagation of Jatropha plant is considered as tremendously limited. One other difficulty faced with great concern is the rate of vegetative growth of this plant and the seed yield. Regardless of the plentiful vegetative growth of the plant, the main concern about this plant is that the production number of the seed per plant is considered low and the seeds show a limited feasibility, which makes it reduce by 50% within 15 months (Kochhar et. al., 2008). Kochhar et. al. studied on how the Jatropha plant is propagated , comparing the performance of seed-raised and cutting-raised of the plant under field conditions and studied on relationship between their rooting and growth behavior to overcome the problem of the disadvantages of the plant.

2.3.1. Jatropha curcas – The advantages of nurturing

Besides the advantages discussed above, cultivating Jatropha plant has a lot more advantages in terms of its characteristics and properties:

- Jatropha is a quick yielding plant on poor land conditions, degraded and unproductive lands under forest and non-forest use, dry and drought flat area, marginal lands and agro forestry crops (Prueksakorn et. al., 2010).
- Jatropha can be a useful plant material for eco-restoration for all types of wasteland.
- Jatropha is considered not a good food material.
- Jatropha grows promptly from plant cuttings or seeds up to the left of 3-5 m.
- Jatropha is extremely pest and disease resistant.
- Jatropha eliminates carbon from the ambiance that stores it in the woody tissues and supports in the build up of soil carbon (Jain & Sharma, 2010).
- The fibers of Jatropha may be useful as binder for construction materials as well as some parts of the plant contains useful components for pharmaceutical and medicinal purposes (Manurung et. al., 2009).

Fresh Jatropha oil is known as slow-drying, unscented and colorless oil, but eventually it will turns yellow after some period. The fact that Jatropha oil cannot be used for nutritional purposes without detoxification makes its function as energy or fuel source very desirable (Agarwal, 2007).

Jatropha *curcas* cultivation has not only offers benefits to the environment but it also contributes its functionality in terms of economic, geopolitics and community. Jatropha plant will be able to diverse the farmers income sources as a supplementary crop to the existing set of farmers activities, appropriate in different cropping systems (Atchen et. al., 2010). Since Jatropha is grown as a boundary fence or living fence, farmers can stop worrying about grazing animals, as it keeps out the animals' ecological restoration or food crop protection due to its inedible to living things (Kochhar et. al., 2008). Other than that, the farmers can keep a tight rein on their initial investment while control their start up risk. The narrow scale of the initiatives retains only minor risk of environmental influence on biodiversity, ecosystem functions and hydrological balance. A community-based method is doubtful to oblige the farmers to unsustainably convert natural lands to Jatropha at large scale (Atchen et. al., 2010).

Malaysia is known to own an adequate area of land as well as good climatic condition which is able to promote the cultivation of Jatropha that can be one of the sources of biodiesel production. There were a total of 1712 ha land areas that were identified for primary production of Jatropha in Malaysia. Some local private companies employed in Jatropha cultivation scaling from 400 ha to 1000 ha. Expectations from the project owners are to increase the cultivation up to 57,601 ha by year 2015. The Ministry of Plantation Industries and Commodities has allocated 300 ha to pilot a project on Jatropha cultivation (Mofijur at.el., 2012).

2.4. Techo-economic analysis of Jatropha biodiesel

There are only several studies made on the techno-economic assessment on the production of Jatropha biodiesel. One of the studies similar to this project paper is by Oforo-Boeteng Cynthia and Lee Keat Teong in 2011, whereby the price of Jatropha biodiesel production calculated was estimated to be $0.99/l with the biodiesel production plant capacity was 13849 tons in Ghana. The total production of Jatropha biodiesel was calculated to be $1456 that is estimated around 10 – 15% of the capital cost per year.

Another one similar study made by Pierrick Bouffaron et. al. (2012), estimated Jatropha biodiesel production cost to be $0.67/l by applying 2200 tons of biodiesel production plant capacity. Pierrick used a computer-based decision support tool called JEALE (Jatropha Economic Assessment for Local Electrification) designated to estimate the economic viability of Jatropha oil production and use for rural electrification.

CHAPTER 3: METHDOLOGY

3.1. Conceptual Design

Starting from gaining the feedstock seed until ending it with the consumption of biodiesel, the life cycle for biodiesel production can be analyzed. This comprises analyzing the extraction of raw materials, energy consumption, emission, as well as analysis of costing during the process of life cycle. As shown in Figure 3.1, the life cycle can be divided into three different aspects; agricultural, production and consumption processes. The focus of this paper is on the costs related to the biodiesel production with a typical production system as shown in Figure 3.2.

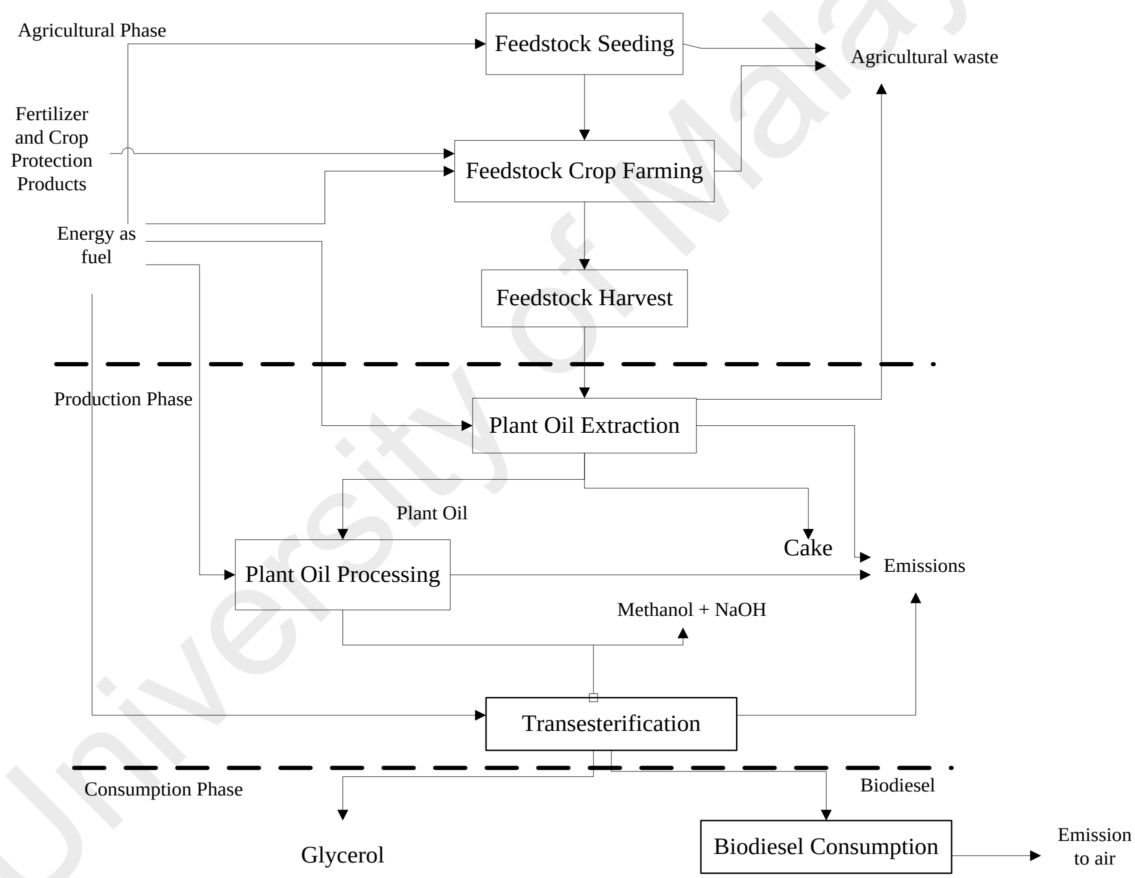


Figure 3.1: Life cycle analysis diagram for biodiesel production (Ong et. al., 2012)

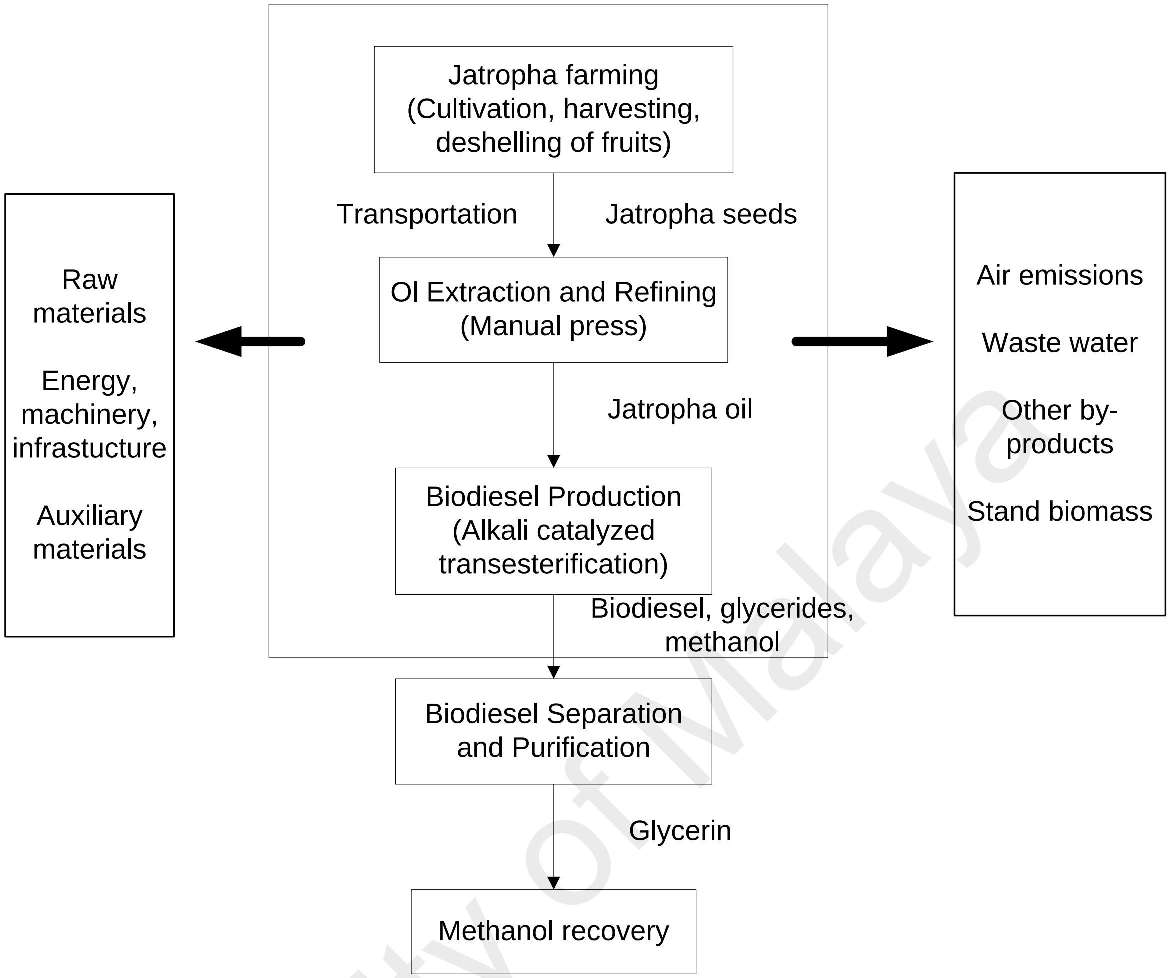


Figure 3.2: Biodiesel production system diagram (Cyhthia & Lee, 2011).

3.2. Data Collection

Collecting data is the important part of this study. Most of the data collected were taken from final report of Asia-Pacific Economic Cooperation (APEC) on Biofuel Costs, Technologies and Economics in APEC Economics (December 2010). Some data were also collected from technical notes and research papers that follow the current market prices.

The initial installation cost, also known as capital cost of biodiesel production plant, normally is referred on the capacity of the production. This also includes the land area needed, equipment and instrumentation needed as well as the building construction needed for the plant. To identify which capital cost is suitable for certain and different plant capacity, Figure 3.3 indicates the lowest, average and highest initial capital costs for biodiesel plant (Ong et. al., 2012).

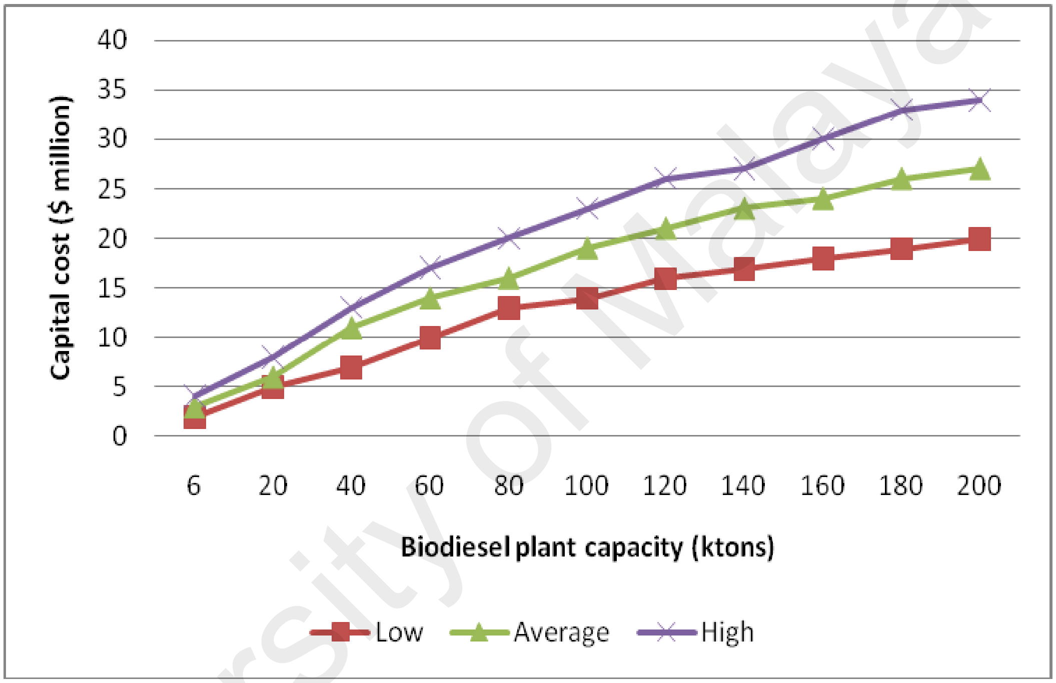


Figure 3.3: Initial capital cost of biodiesel plant based on plant capacity (Ong et. al., 2012).

Crude jatropha oil (CJO) was used as biodiesel production feedstock in this project paper. It is known that the average price of crude jatropha oil was about $300/ton in 2006 based on Figure 3.4. However, the price has increased quite rapidly in 2008 with an average price of $750/ton. As of January 2010, the average price of crude jatropha oil fell to about $500/ton (APEC, 2010).

3.3. Economic indicator

The project was assumed to be operating at 100% capacity throughout the whole project lifetime, and the project lifetime has been fixed to be 10 years, including one year for starting-up the plant and construction. Table 3.1 below shows the summary of economic data and indicators. The justification of the data given below was collected from various sources from previous studies as indicated at the bottom of Table 3.1.

Table 3.1: Summary of economic data and indicators

Item	**Data**
Project lifetime	10 years
Plant capacity	50 ktons
Initial capital cost	$12 million
Depreciation model	10% annually
Operating Rate	$110/ton
Maintenance Cost	2% of capital cost annually
Replacement Cost	$10 million
Taxes	10% of biodiesel sales
Crude jatropha oil price	$447/ton
Glycerol price	$0.1/kg
Interest Rate	8%
Biodiesel conversion efficiency	95%
Glycerol conversion factor	0.0955

Source: Ong et. al., 2012; May et. al., 2011; Jain & Sharma, 2010; APEC, 2010; P. Bouffaran et. al., 2012.

With the data collected from various sources according to the latest market prices, the calculation of techno-economic analysis of biodiesel production from Jatropha curcas plant is based on the method used by H. C. Ong et. al. (2012) in calculating the life cycle cost and sensitivity analysis of palm biodiesel production.

3.4. Life Cycle Cost

The economic advantage of Jatropha curcas is assessed by life cycle cost analysis. There are six parameters to develop the life cycle model for biodiesel production from Jatropha curcas and it is as follow:

LCC = Capital Cost + Operating Cost + Maintenance Cost + Feedstock Cost – Salvage Value – By Product Credit

In business and economics sectors, the present value calculations are usually applied to evaluate cash flows at different times with the method used here. Generating the life cycle cost in terms of a present value model gives,

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

The method of calculation for operation cost (OC), maintenance cost (MC), feedstock cost (FC), salvage value (SV), and by-product credit (BP) are discussed further below.

3.4.1. Present worth Factor

Present worth factor (PWF) is value by which the future cash flow is collected in order to attain the current present value of the project. The present worth factor is applied to determine the feasibility of biodiesel production plant investment for a given rate of interest. The present worth factor in year *i* is defined as,

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

Total this up over a project life of n years will generate the compound present worth factor,

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

3.4.2. Capital cost

The considerations that includes in the capital costs are the required land, building construction, instrumentation and equipment needed for the plant. The initial installation capital cost depends mostly on the biodiesel plant capacity. Figure 3.3 shows the initial capital costs by annual biodiesel plant capacity suggested by Howell S. (2005). According to this figure, for an annual biodiesel production capacity of PC = 50 ktons, the estimated project capital cost is CC = $12 million.

3.4.3. Operating cost

For operating cost, the costs of utilities, labour, laboratory services, transportation, administration, supervision, factory expenses, other materials and energy flows except those of the CPO feedstock needs to be included. The costs related with waste water treatment and sludge waste processing to remove residual acids and other contaminant (e.g. methanol and NaOH) are also included in operating cost. 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 cost will be,

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

3.4.4. Maintenance cost

The annual periodical maintenance and service cost is assumed to be MR = 2% of the initial capital cost. This value is taken to be constant over the entire project lifetime. The maintenance cost is computed over the life time of the plant as,

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

3.4.5. Feedstock cost

Annual feedstock consumption is determined by adjusting the plant capacity by the feedstock to biodiesel conversion efficiency,

$$FU = \frac{PC}{CE}$$

According to the historical price of crude Jatropha oil in Figure 3.4, crude Jatropha oil price is estimated to be FP = $ 477 / ton by taking the five years (2005 – 2009) average price for the plant (APEC, 2010). This is assumed invariable over the life of the plant. The sensitivity to this assumption is discussed in the next part. Based on the price, total cost of the feedstock over the life of the plant is given as follow,

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

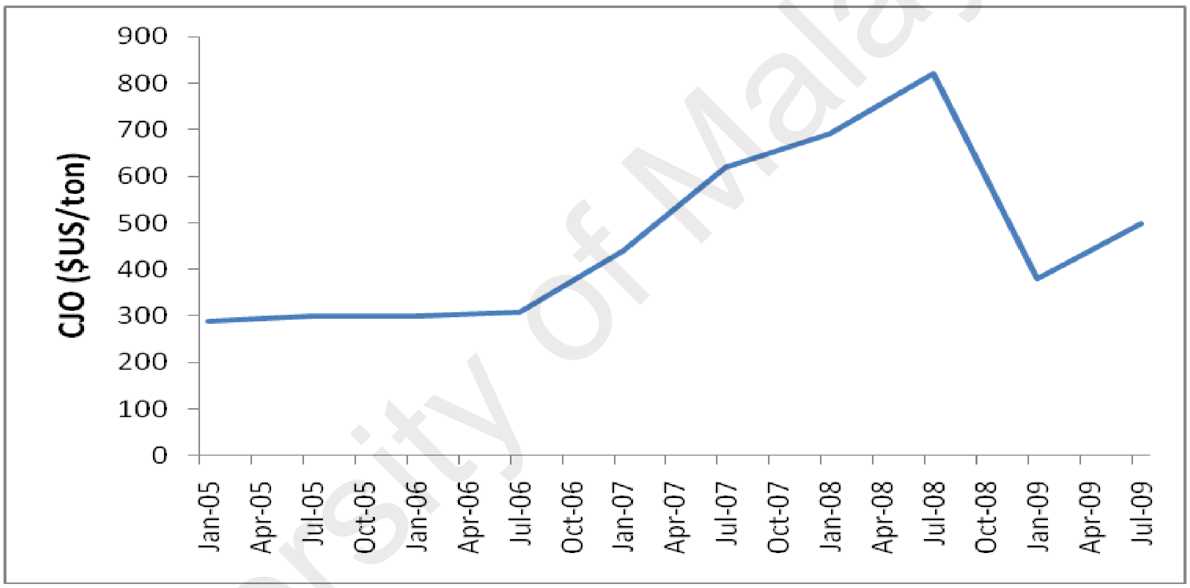


Figure 3.4: Historical price of crude jatropha oil from 2005 to 2009 (APEC, 2010).

3.4.6. Salvage value

The salvage value is the left over value of the components and assets of the planet at the end of the project lifetime. In this study, it has been assumed earlier that the depreciation rate, *d* is 10% and it occurs per annum. The salvage value model is established based on the replacement cost rather than the initial capital cost and is as followed by,

$$SV = RC(1-d)^{n-1}$$

So, the present value of salvage cost can be calculated as,

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

3.4.7. By product credit

Glycerol is produced during the process of biodiesel production. Glycerol can be sold as a useful by-product. The calculation for a by-product is referred by setting a fixed price for glycerol with production determined by a plant capacity to glycerol conversion factor. Value of the credit over the life of the plant is as follow,

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

3.5. Payback period

The payback period is described as the time taken to gain a financial return equivalent to the amount of the original investment cost. The payback period is a simple method of assessing the viability and feasibility of the investment. The method of the payback applies the ratio of capital cost over the annual earning as an attempt to observe the project. The percentage of the total biodiesel sales includes the taxes. The expression below is used to calculate the payback period,

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

3.6. Sensitivity analysis

Sensitivity analysis is defined as a study on how the estimated performance differs with change in main assumption on which the estimations are based. Furthermore, it allows investigation on the uncertainties, such as the international prices, can change the result of the project. The significant variables for this project are the price of crude jatropha oil; which is the most significant variable; interest rate, initial capital cost, capital cost as well as the oil conversion yield. The crude jatropha oil shall follow the market value and can be presumed to be sensitive to global biodiesel production if development takes place in this sector is expected, which could result in two different conclusions. First conclusion is, if the producers of jatropha oil increase production in advance of growth in biodiesel capacity, CJO will probably drop. The second conclusion is, if biodiesel production capacity surpasses CJO production, the price of CJO will probably increase. The supply of crude oil and demand side factors can also provide for biodiesel production cost through changes in the quality of the production as well as yield if there is changes happens in the quality of crude (Ong et. al., 2012).

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Life Cycle Cost Analysis and Payback Period

The life cycle cost is calculated for a typical 50 ktons of biodiesel plant located in Malaysia using the data tabulated in Table 3.1. Results are shown in Table 4.1 and Figure 4.1.

A shown in Table 5, the life cycle cost of jatropha biodiesel production is estimated $315 million, which yields a jatropha biodiesel unit cost of $0.661/l. Compared to palm biodiesel production obtained by HC Ong et. al. (2012), the price is much higher which is $665 million, yields $0.632/l of palm biodiesel unit cost. It is also much higher than the fossil diesel price in Malaysia retailed currently $0.58/l (HC Ong et. al., 2012).

The cost of jatropha biodiesel production in this study is higher than Pierrick Bouffaron et. al. (2012) obtained, whereby the jatropha biodiesel production cost obtained was $0.67/l but with a biodiesel production plant capacity of 2200 tons only. In a study made by Cynthia and Lee (2011), with a biodiesel production plant capacity of 13849 tons, the total cost for jatropha biodiesel production was $0.99/l, which is higher than this study.

Table 4.1: Summary of total production cost and payback period of jatropha biodiesel production plant

	Life cycle cost ($)	**Unit cost ($/l of biodiesel)**
Total capital investment	12,000,000	0.0273
Crude jatropha oil cost	254,106,388	0.5327
Operating cost	55,669,010	0.1167
Maintenance cost	2,429,193	0.0051

Salvage value	3,874,205	0.0040
By product credit	4,833,082	0.0101
Total biodiesel cost	315,497,304	0.6614
Payback period (year)		2.69

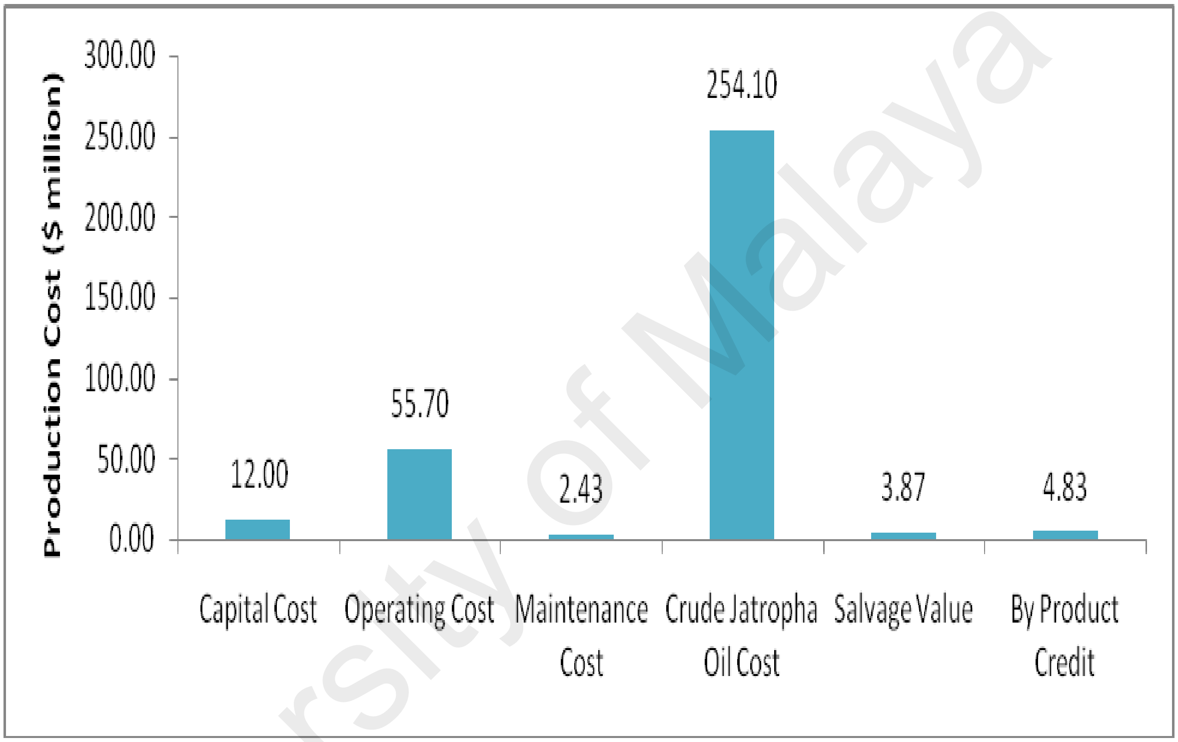


Figure 4.1: Distribution of jatropha biodiesel production cost.

Looking at the graph in Figure 4.1, the feedstock cost (CJO) corresponds to be the biggest part in the final cost of biodiesel production. The feedstock cost takes about 80% of the total production cost, which costs about \$0.53/l in total. This is followed by the operating cost, which costs about \$0.12/l. Over the lifetime of the project, the glycerol by-products sale put in about \$4.83 million of total production cost.

The payback period of this project, which initiated from 50 ktons of jatropha biodiesel production plant, was found to be around 2.69 years. It is found to be less than one third of the 10 years project life, which denotes that the project is economically feasible.

4.2. Sensitivity Analysis

The result of the sensitivity analysis is indicated in five different variables as shown in Figure 4.2. The five variables are the feedstock price (CJO), interest rate, oil conversion yield, operating cost as well as the initial capital cost. The legend on the left of Figure 4.2 indicates the variation in the sensitivity variable, starting from favourable, to planned, to unfavourable. Similar to the life cycle cost analysis did earlier, it is expected that the variation in the price of CJO corresponds to as the main impact on the life cycle cost but as seen in the figure for favourable and unfavourable indicates drastic difference. The present value interest rate and the oil conversion yield show only small difference between favourable and unfavourable. The operating costs variation is shown to have the minimal impact on the current costs but simultaneously can compensate large variation in CJO price. In order to reduce the total biodiesel production costs, constant improvement in the biodiesel conversion processes as well as better efficiency in operating should be implemented.

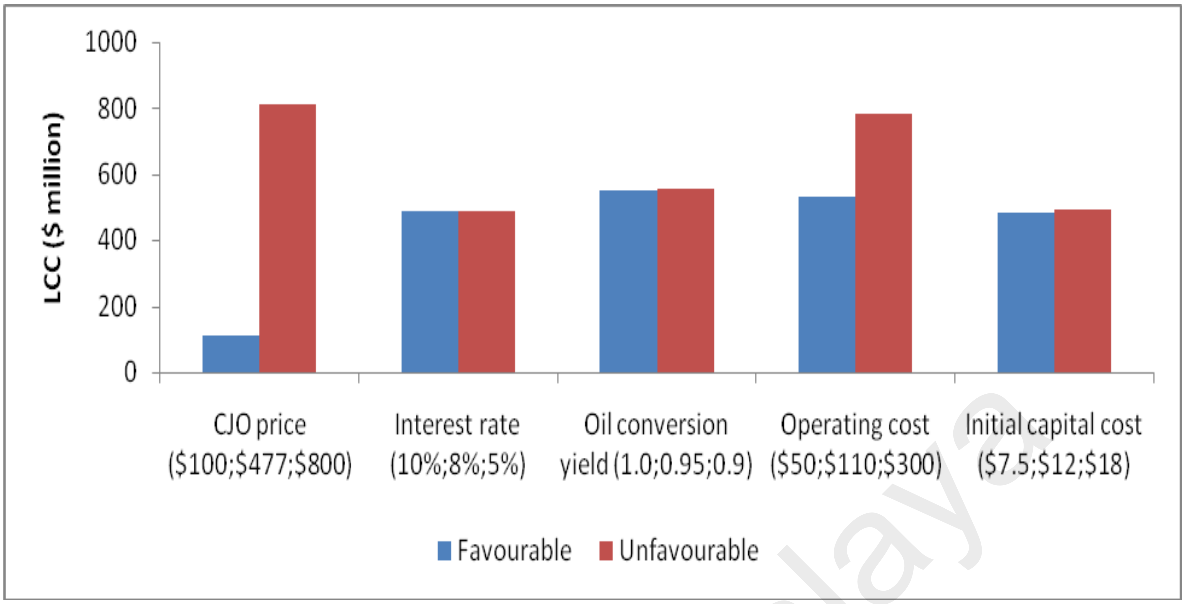


Figure 4.2: Sensitivity analysis of life cycle cost for jatropha biodiesel production.

Due to its significance in establishing the cost of biodiesel (per litre) produced, further analysis was done on the outcome of change in CJO price, as shown in Figure 4.3. According to this figure, it is seen that CJO price linear relationship with the biodiesel production cost, whereby an increment of CJO price by $0.10/kg will cause a $0.10/l rise in biodiesel production cost.

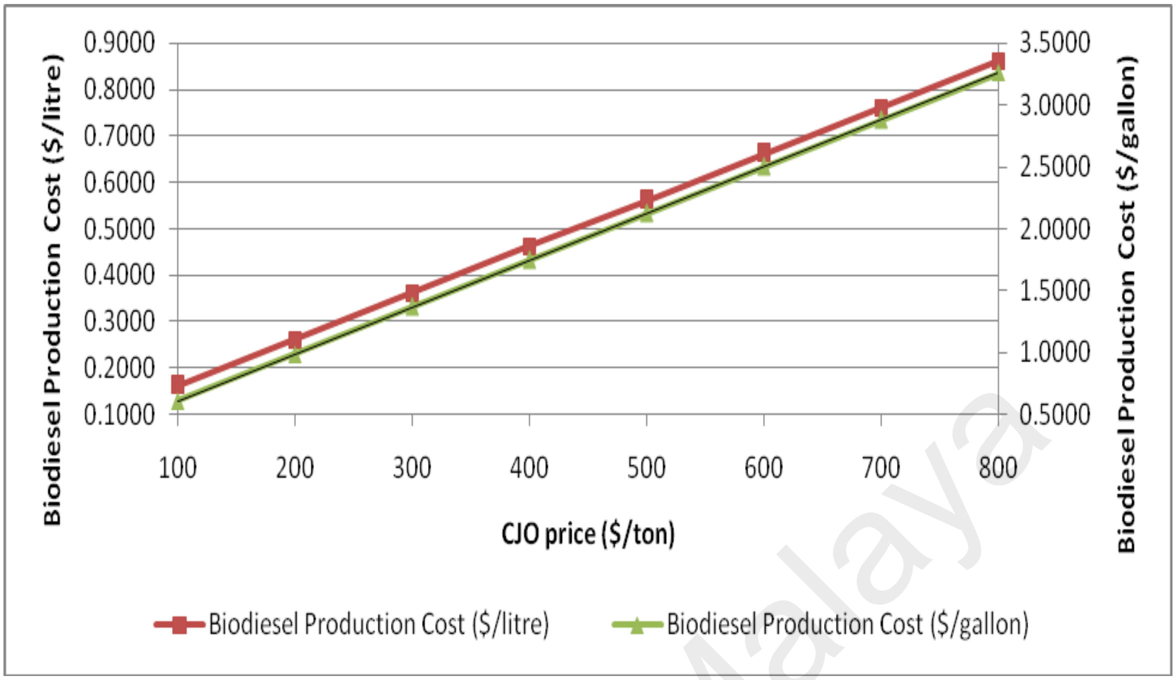


Figure 4.3: The impact of crude jatropha oil on the biodiesel cost.

4.3. Biodiesel Taxation and Subsidy Scenarios

The final biodiesel cost is presented by taxation and subsidy scenarios in this last section of the overall results. The comparison between the final biodiesel price and the fossil diesel are tabulated in Table 4.2 at a different taxation and subsidy scenarios. The different scenarios considered are total tax exemption, 15% taxation, a subsidy of \$0.10/l as well as \$0.18/l for biodiesel in comparison with the price of fossil diesel. The \$0.10/l and \$0.18/l of the subsidy cost were selected based on the current subsidy cost for diesel and petrol in Malaysia, respectively. At the same time, the fossil fuel price is taken based on the retail price of diesel in Malaysia, which is \$0.58/l. To identify the fuel consumption substitution ratio of jatropha biodiesel to fossil diesel, which needs to be taken into account for calculation, the energy content of both jatropha biodiesel and fossil diesel are known to be

39.9 MJ/l and 35.1 MJ/l respectively. So, the fuel consumption substitution ration of jatropha biodiesel to fossil diesel is 0.88. The results tabulated in Table 4.2 shows that the final cost of biodiesel with subsidy of $0.10/l and $0.18/l are much lower compared to fossil diesel.

Table 4.2: Biodiesel taxation and subsidy level scenarios at current production cost.

$/l	**Biodiesel total tax exemption**	**Biodiesel 15% of taxation**	**Biodiesel with subsidy $0.10/l**	**Biodiesel with subsidy $0.18/l**	**Fossil diesel**
Production cost ($/l)	0.661	0.661	0.661	0.661	0
Taxes/subsidy ($/l)	0	0.099	0.100	0.180	0
Total ($/l)	0.661	0.760	0.561	0.481	0.581
Total cost including fuel substitution ratio	0.582	0.669	0.494	0.423	0.581

The taxation and subsidy scenarios of jatropha oil based on biodiesel production cost as a function of the CJO price can be seen in Figure 4.4. According to the figure, biodiesel is seen to be as competitive as fossil diesel if the CJO price is below $0.50/kg with the exemption of tax. It is also can be seen that if the biodiesel subsidy of either $0.10 or $0.18, the price of CJO could attain $0.60/kg and $0.70/kg correspondingly so that the competitiveness between biodiesel and fossil diesel can be preserved. On the other hand, according to the figure, although biodiesel subsidy $0.18/l is provided, CJO price rises up to $0.70/kg, which makes the price of biodiesel production higher than fossil diesel.

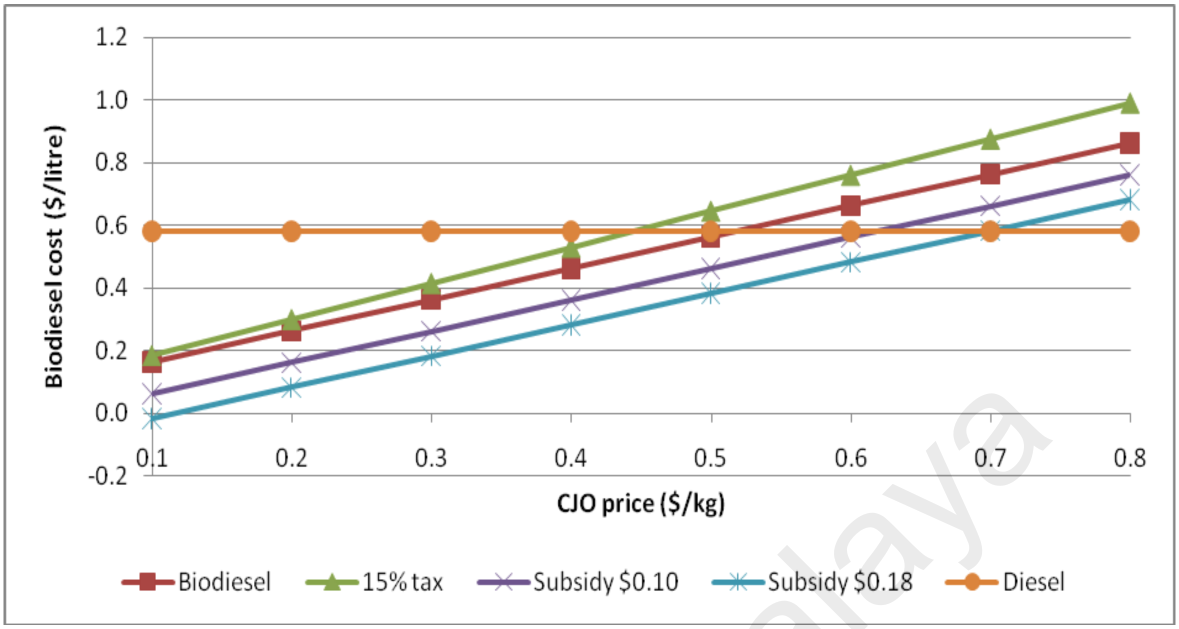


Figure 4.4: Taxation and subsidy scenarios of biodiesel production cost on CJO price.

CHAPTER 5: CONCLUSIONS

This project paper has done a techno-economic and sensitivity analysis on biodiesel production from jatropha *curcas L.* oil in Malaysia. Taken the model of life cycle cost as well as the sensitivity analysis as 50 ktons of biodiesel plant, the growth and assessment were done for 10 year plant life. The model used in this project paper is flexible and can be apply to any plant capacity, any feedstock and production cost, capital cost, and other kind of variables.

As per discussed in the results and discussion section, it was calculated that the biodiesel production plant life cycle cost is estimated to be $315 million which yields a jatropha biodiesel unit cost of $0.661/l over the project lifetime. The payback period was found to be 2.69 years, which was about less than one third of the project lifetime.

Jatropha biodiesel has been proven to be feasible economically compared to palm biodiesel. It is recommended that in order to process and produce jatropha biodiesel, the oil used should be in large quantities as the production cost to produce it is costly. It is proven in India that to produce crude jatropha oil on commercial basis is less costly. Therefore, biodiesel production from jatropha oil is feasible especially in multi-functional platforms that can maintain the engines to keep running for a long time. Hence, if 1 ton of biodiesel can be produced from jatropha at a minimal cost, then on commercial basis, by the time this quantity is normalized to a desired capacity, the marginal profit will be reported after the payback period of not more than three years.

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