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Energy Saving Potential using Elite Jatropha Curcas Hybrid for Biodiesel Production in Malaysia

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Abstract: The world continues to search for renewable energy resources, due to the devastating effect of global warming and the dwindling resources of fossil fuels. Without needing much modifications to the existing diesel engines, biodiesel is regarded as one of the most promising ways to treat these two issues simultaneously. However, the production of biodiesel is always associated with a higher cost compared to its counterpart; the petroleum-derived diesel. In addition, the type of feedstock used in the production of biodiesel also has also become a big concern due to the never-ending fuel vs food debate. Jatropha curcas is a second generation feedstock which can be specifically grown to avoid the usage of edible oils as feedstock to produce fuel. In this paper, the energy saving potential of using elite Jatropha curcas hybrid for biodiesel production in Malaysia are evaluated by conducting a full chain energy analysis. It was found that the new hybrid consumed 25.32 MJ of energy in order to produce 1kg of biodiesel. The net energy balance (NEB) and net energy ratio (NER) when by-products are not utilized are found to be 15.89 MJ/kg and 1.63, respectively. However, the NEB and NER increase to 26.72 MJ/kg and 2.84 when the by-products are used in the biodiesel conversion process. Hence, this new hybrid of Jatropha curcas has a huge potential to be used for the production of biodiesel.

Keywords: Biodiesel, Energy ratio, Renewable energy.

I. INTRODUCTION

Dwindling resources of fossil fuels and threatening effect of global warming due to anthropogenic CO_2 emission force the world to continue searching for renewable, alternative energy sources.

A growth of 2.2% in the world's energy consumption was recorded in 2017, the fastest growth since 2013 and an estimated 1.6% increase in CO_2 emission was recorded in the same year [1].As of the end of 2013, it is predicted that the Earth has just enough reserve of nearly 1.688 trillion barrels of crude oil that could extracted for the next 53.3 years based on the current extraction rate [2].However, this could be sooner than expected, since the demand for oil continue to increase. It is reported that petroleum demand grew by 1.7 Mb/d for 2017, significantly higher than the 10-year average of approximately 1.1 Mb/d, and it is predicted that the global energy consumption would rise to 53% by 2030 [1]. Meanwhile, it was agreed by The Intergovernmental Panel on Climate Change (IPCC) that the CO_2 emission should be decreased to at least 50% in order to ensure the rise of the world's average surface temperature is capped at 2^{o}C by 2050 [3]. It is believed that if the global temperature rise exceeded 2^{o}C, hundreds of millions people could die, and up to one million species would face extinction [4]. Both fossil fuel depletion and global warming issues are interconnected between one another. Biofuel in the form of bioethanol and biodiesel is seen as one of the promising ways to solve those simultaneously. This form of renewable energy has moved from being a niche market into the mainstream market. Giant energy producers are also investing a lot in this sector, and a significant hike in biodiesel production can be observed globally, where 0.84 billion liters were produced in 2000 and the production skyrocketed to 32 billion liters in 2014 [5, 6]. Biodiesel is considered as a promising alternative to petro-diesel since it can be used directly in most current diesel engines available in the market [7]. Pure biodiesel, or 100% biodiesel is referred to as B100, and it is quite common for biodiesel to be blended with petro-diesel. When blended, it is commonly known as B*xx*; where *xx* indicates the amount of biodiesel used in the blend. For example, B20 means a mixture of 20% biodiesel and 80% petro-diesel. B20 biodiesel and lower blend ratio are widely traded globally; although it is reported that a pure biodiesel B100 can also be used with only slight or no modifications of the engines [8].

One of the main advantages possessed by biodiesel is the lower pollution level of the emission when utilized. This is important since transportation sector is among the biggest contributors to greenhouse gases emission in most developing and developed countries, after taking into consideration in which 58% of the global fossil fuel usage is directly related to that particular sector [3, 9].

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Even though there are evidences showing slight deterioration of compression ignition engines when biodiesel is used, the overall environmental aspect improved tremendously based on the same study [10].However, the production of biodiesel does not come without its own set of challenges. One of the main issues is the overall cost associated in its production;

where it is usually substantially higher than the market price of its fossil fuel counterpart. For example, the cost to produce biodiesel using microalgae is roughly around $2.00 per liter [11], while $0.99 per liter by using palm oil as the feedstock [12]. The situation is even worse in developed countries, where it is reported that the cost to produce biodiesel is 1.5 to 3 times higher than the cost to process petro-diesel due to the insatiable need for edible oils [8]. Hence, selection of feedstock plays a crucial role in keeping the cost low for biodiesel production. In this paper, the potential of using elite Jatropha hybrid as feedstock for biodiesel production in Malaysia is evaluated through meticulous energy balance calculations.

II. FEEDSTOCK FOR BIODIESEL PRODUCTION

Biodiesel is produced when natural triglycerides contained in feedstock such as waste materials [13], animal fats [14], microalgae [15], and plant [16] undergo a process called transesterification. This process involves the mixture of the feedstock with short-chain alcohols (eg methanol and ethanol) with the presence of catalyst. Among the factors considered when evaluating the potential of a certain feedstock to be used in the mass production of biodiesel in a specific region are climate, geography of the land, socio-economy, and type of the available soil [17, 18].

Considering the variation of feedstock that can be used, biodiesel production is often linked to the classic food versus fuel dilemma; where it is extensively debated whether fuel should be prioritized over the global supply of food. Edible crops such as soybean and corn are considered as first generation feedstock; and the usage of these for the production of biodiesel would pose as threat to global food security [19]. Currently, there is a dire need for second generation feedstock since 95% of the current feedstock for biodiesel production comes from edible sources; and up to a third of edible oils produced globally in 2017 is used for this purpose [9]. Looking from this perspective, second generation feedstock is generally viewed as one of the available pathways not to disturb the cultivation of crops to be used as food. Second generation feedstock such as animal fats, woody crops, waste cooking oil, agricultural waste, and non-food energy crops specifically grown on lands unsuitable for the growth of edible crops are considered as highly potential candidates to produce biodiesel sustainably [20].

Palm oil is the primary feedstock used in Malaysia for the production of biodiesel [5], and B10 biodiesel is commercially available for diesel-powered automotive. However, due to the eagerness of the world in finding other potential feedstock, non-edible oils such as *Jatropha curcas*, *Millettia pinnata*, *Ceiba pentandra*, and *Calophyllum inophyllum* are gaining attentions from the scientists [21, 22]. Advancement of technology allows these second generation feedstock to become serious contenders as low cost feedstock for biodiesel productions [23]. Utilization of cheap feedstock is crucial since roughly 75% of the cost incurred in the production of biodiesel is the cost of the feedstock used, as shown in Fig. 1 [6]. While keeping the initial investment cost low, biodiesel can be processed at a substantially lower price, hence making it more desirable and competitive with petro-diesel.

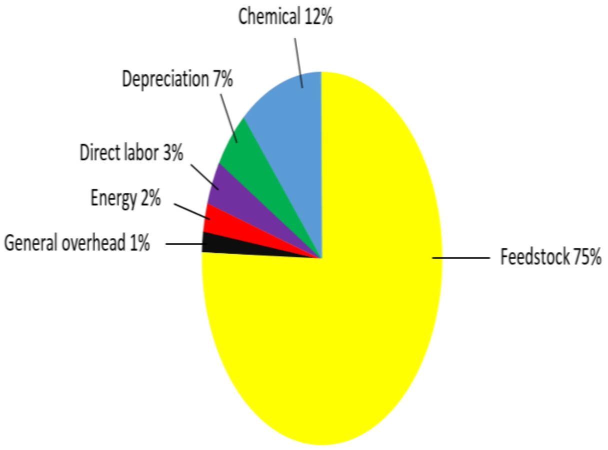

Fig. 1 The breakdown of cost in biodiesel production

Practicality of utilizing *Jatropha curcas* for biodiesel feedstock in Malaysia

Jatropha curcas (thereafter referred to as *Jatropha*) comes from the family of Euphorbiaceae, a type of highly adaptable sub-tropical flowering plant that thrives excellently in semi-arid land. This is a big advantage in biofuel industry since lower maintenance cost during the farming process is always favorable. Despite the fact the plant can be grown with little water, it has been proven that a higher oil yield can be obtained when optimal cultivation method is employed [24]. Due to the warm and humid climate in Malaysia; coupled with occasional dry seasons, *Jatropha* can be considered as an ideal plant to be cultivated and maintained to be used as commercial biodiesel feedstock in Malaysia. In addition, the cultivation can be done in ‘wasteland’ areas not suitable for other types of plants as an effort to reclaim the land and curbing erosion, thanks to the plant’s robustness [25]. Depending on the implemented conversion process, various forms of fuel can be obtained from *Jatropha* oil, such as biogas, bioethanol, and biodiesel [26, 27]. The oil content in *Jatropha* varies depending on the soil and weather conditions. With 27-40% oil content, averaging at 34.4%, *Jatropha* is an ideal candidate to be used for biodiesel production [28]. In some investigations, the oil content of its fruit is reported to be as high as 66.4% [29]. Apart from that, fatty acid composition also plays a huge factor when selecting a particular type of feedstock. This is important as fatty acid composition strongly influence the overall quality of a biodiesel (such as cetane number, kinematic viscosity, density, and heating value); and this is one of main reasons why some feedstock are favored over the others [30, 31].

The rich content of fatty acid in *Jatropha* oil is illustrated in Table 1; along with other types of feedstock as comparison [32].

Table. 1 Comparison of fatty acid composition (%) in different types of feedstock

Fatty acid type	Sunflower oil	Soybean oil	Palm oil	*Jatropha* oil
Monounsaturated	21.1	23.4	39.2	45.4
Polyunsaturated	66.2	61.0	10.5	33.0
Saturated	11.3	15.1	49.9	21.6
Oleic	21.1	23.4	39.2	44.7
Linoleic	66.2	53.2	10.1	32.8
Palmitic	-	11.0	44.0	14.2
Stearic	4.5	4.0	4.5	7.0
Linolenic	-	7.8	0.4	0.2
Myristic	-	0.1	1.1	0.1

Consequently, the characteristics of the emissions from the combustion of biodiesel differs depending in the types and origins of the utilized feedstock [33]. Biodiesel derived from *Jatropha* is gaining attention globally due to its compliance with the available biodiesel standards such as the European Committee for Standardization's EN 14214 and the American Society for Testing and Materials Standard Specification for Diesel Oil (ASTM D6751) [34, 35]. Table 2 shows the characteristics of petro-diesel and *Jatropha* biodiesel compared to the ASTM D6751 standards [36].

Table. 2 Properties of petro-diesel and Jatropha biodiesel compared to ASTM D6751 standard

Property	Diesel	Jatropha biodiesel	ASTM D 6751
Acid value (mg $KOHg^{-1}$)	-	0.29	<0.80
Kinematic viscosity at 40^oC (mm^2s^{-1})	2.6	2.9	1.9-6.0
Flash point (^oC)	68	140	>130
Specific gravity (g ml^{-1})	0.85	0.89	0.86-0.90
Water content (%)	0.02	0.01	<0.03
Ash content (%)	0.01	0.01	<0.02

Jathropa is among the plants which possesses the quality to be used in the production of biodiesel in Malaysia. An estimated area of 32.9 million acres has been identified to have the potential for *Jatropha* plantation; which in the first three years, an acre of land is predicted to have a fruit yield of 3.6 metric tons, and multiplied after the third year [37]. With all the good qualities possessed by *Jatropha*, it is not surprising why it is considered as among the highly potential feedstock for biodiesel production.

Challenges in using *Jatropha* as feedstock

Even though *Jatropha* is loaded with qualities that enable it to be extensively utilized as feedstock, there are reports questioning the sustainability of *Jatropha* for biodiesel production [38]. As an example, India still fail to fulfil the national implementation of 20% *Jatropha* biodiesel and petro-diesel blending through their National Biodiesel Mission despite the widespread of *Jatropha* cultivation since 2003 [39]. Contrary to the initial notion that *Jatropha* is a pest resistant and hardy plant, there are reports on the vulnerability of *Jatropha* to diseases and pest attacks, as experienced by farmers in Senegal [40], India [41], and South Africa [42]. While in Rwanda, even with the establishment of Institute of Scientific and Technological Research (IRST), 80% of the *Jatropha* farmers experienced lack of support from the government, up to a point where 33% of them reported a very low fruit yield of only 0 to 1.0 t/hectare/year [43]. This leads to the failure to meet one of the most crucial parameters to justify the usage of a particular feedstock; which is oil yield per hectare. *Jatropha* fruit yield patterns all across the continents also seem be less than encouraging. It has been agreed that in order to have a decent potential, a fruit yield of 3.75 t/hectare/year, coupled with 30 – 35% oil content and an 1.2 t/hectare oil yield are required for *Jatropha* to exceed the yield of soybean (0.38 t/hectare) and rapeseed (1.0 t/hectare) [44]. When this criteria are compared to the actual yield from various countries, it can be concluded that the numbers are far from what has been initially anticipated [45]. In the same study, in addition to various natural factors as unsuitable climate and pest attacks, it is concluded that the perceived 'epic failure' mainly revolves around factors such as lack of support and technical guidance from government agencies, insufficient skilled farmers, lack of favorable biodiesel policies from the government, and misunderstanding between farmers and interested parties. These actual results are proven to be disappointing due to all the expectations and hypes regarding this plant, which was once hailed as a magic plant in the field of biofuel. However, under closer observation, it is found that most of the factors contributing to the failures are related to the government and organization of the plantation; not the problem with the plant itself. There are recent reports on the need to continue enhancing the cultivation and processing technologies due to the huge potential of this plant [46, 47].

This is further supported by the fact where *Jatropha* biodiesel projects in various places such as Honduras, Cuba and Mozambique have been executed successfully [45, 48].

Hence, more study must be conducted extensively in order to increase the success probability of the project at a specific location [49, 50].

III. METHODOLOGY

The objective is to evaluate energy saving potential from elite intraspecific hybrids from selected *Jatropha* accessions[51]. A full chain energy analysis is used to estimate the *Jatropha* hybrids prospective for feasible biodiesel production in Malaysia. A total of 21 accessions originated from 8 different countries in Southeast Asia are cultivated under standard agricultural practice. The system boundary consists of complete life cycle of *Jatropha* biodiesel starting from agricultural phase through seed processing up to biodiesel storage. Accession selection is determined by full chain energy analysis, including energy consumed in production and application of input materials, such as fertilizer, pesticides, fuel for machinery, human labor, etc. Energy outputs from biodiesel and co-products are included in the analysis, for example husk, seed cake and glycerine. Two indicators for measuring the energy efficiency of biofuels are net energy balance (NEB) and net energy ratio (NER) as given in the following equation.

$$NEB = Energy\ output - total\ energy\ input$$

$$NER = \frac{Energy\ output}{Total\ energy\ input}$$

NEB is the difference between energy output and input, while NER is the ratio of energy output to energy input. In this case, the energy output is the biodiesel energy content. The NEB and NER value must be positive and greater than 1 to indicate energy gain from production of biodiesel from *Jatropha* in Malaysia. The energy factors for analysis are shown in Table 3; where value for chemical production are generally adapted from the literature because most are imported [52-54]. Importantly, the energy factors related to agricultural activities are sourced from Malaysia. The functional unit (FU) used is 1 mega Joule (MJ) of energy required to produce 1 kg of combusted *Jatropha* biodiesel. For energy balance analysis, the total energy input is converted into FU by multiplying the amount of material consumed with respective energy factor.

Table. 3 *Jatropha* biodiesel production materials energy factors

Subject	Energy factor (MJ/kg)	
Fertilizer production		
Nitrogen (N)	87.9	
Phosphorus (P)	26.4	
Potassium (K)	10.5	
Pesticide	358	
Glyphosate	452.5	(36.4 MJ/L)
Paraquat	458.4	(8.1 MJ/L)
Diesel energy content	43.1	
Diesel production energy input	9.6	
Sodium hydroxide (NaOH)	19.87	
Wood (air dry)	16.54E-15.5	
JCL biodiesel	37.3	
Seed cake (as fuel stock)	18.8	
Electricity	3.6	
Methanol (MeOH)	38.08	
Sulphuric acid	3.1	
Steam	3.12	
Peel (air dry)	11.1-13.07	
Crude glycerin	25.6	
Seed cake (as fertilizer)	6.22	

IV. CULTIVATION OF ELITE JATROPHA HYBRIDS

Jatropha accessions were grown from cuttings in nursery using 1:1 mixture of soil and compost. The cuttings were transferred to plantation after 4 months with crop density of 2 m x 3 m yielding 2000 trees/ha. Preceding plantation is prepared by tilling, harrowing and furrowing using tractors where it is done only once in *Jatropha* life cycle. After four and eight months, organic fertilizer was applied at rate of 2.5 kg, in which usually supplemented with chicken manure. The used of NPK fertilizer is required to ensure high fruit yield for feasible biodiesel production. Irrigation is necessary as supplement to natural rainfall by pumping of water. Other agricultural management practice was maintained at standard condition to control plants from getting damaged by pests and diseases. Based on literature, fruits are transported by 10-wheel truck of 10 tonnes load capacity with 4 km L^{-1} fuel efficiency.

V. JATROPHA OIL EXTRACTION AND SEED CAKE PRODUCTION

Oil is extracted from *Jatropha* fruit by drying and cracking the peel before feed into screw-press machine.

The extracted oil is then processed with filtering machine to produced *Jatropha* crude oil. Electricity consumption for extraction and filtration is estimated at 75 kWh t^{-1} and producing seed cake as by-product. The cakes can be utilized for production of briquettes which consumed 0.9 t of seed cake, 0.1 t of water and 265 kWh for ton of briquettes produced. Energy output of seed briquettes is only 18.8 $MJkg^{-1}$ and takes about 30 minutes to ignite making it not suitable to be used individually as boiler fuel. Instead it is usually co-fired with fuel oil with only 40% of total fuel required. Detailed information related to *Jatropha* cultivation and oil extraction are given in Table 4.

Table. 4 Input materials for *Jatropha* cultivation and crude oil extraction

Item	Unit	Value
***Jatropha* plantation**		
Plant spacing	m^2	2 x 3
Organic fertilizer	ton ha^{--1} y^{-1}	8
Nitrogen fertilizer as N	kg ha^{--1} y^{-1}	64
Phosphate fertilizer as P2O5	kg ha^{--1} y^{-1}	384
Potash fertilizer as K2O	kg ha^{--1} y^{-1}	51.2
Pesticides	L ha^{--1} y^{-1}	0.43
Glyphosate	L ha^{--1} y^{-1}	1.5
Paraquat	L ha^{--1} y^{-1}	0.552
Human labor	man-days ha^{-1}	5
Transport distance range	km	64
Diesel consumed for transportation	km L^{-1}	10
Diesel consumed for irrigation	L ha-^{1}	70.6
Diesel use for farm machinery	L ha^{1}	16.4
***Jatropha* oil extraction**		
Jatropha oil	kg kg^{-1} seeds	0.33
Seed cake	kg kg^{-1} seeds	0.67
Electricity	kWh kg^{-1} seeds	0.075
Briquettes production		
Seed cake	kg kg-^{1} briquette	0.9
Electricity	kWh kg^{-1} briquette	0.26
Water	Kg kg^{-1} briquette	0.1

VI. BIODIESEL PRODUCTION VIA TRANSESTERIFICATION

Biodiesel is converted from the oil through pretreatment and transesterification. Pre-treatment is conducted by adding methanol with ratio 6:1 and sulphuric acid is used as a catalyst. Potassium hydroxide is then use in base catalyzed transesterification using methanol-to-oil ratio of 5:1.

Electricity consumed during pre-treatment is about 14 kWh $t^{-1}$of crude oil while transesterification and purification of biodiesel consume about kWh $t^{-1}$of treated oil. The conversion efficiency of biodiesel is 95% and the ratio of biodiesel to glycerin is 3.5:1. All material and energy input in pretreatment and transesterification process is included in Table 5 [54-58].

Table. 5 Materials and energy input for *Jatropha* biodiesel conversion

Item	Unit	Value
Pre-treatment		
Methanol	kg t^{-1} crude oil	200
Sulphuric acid	kg t^{-1} crude oil	14
Electricity	kWh t^{-1} crude oil	14
Steam	MJ t^{-1} crude oil	0.85
Transesterification		
NaOH	g kg^{-1} treated oil	10
Methanol	g kg^{-1} treated oil	200
Biodiesel	g kg^{-1} treated oil	970
Phosphoric acid	g kg^{-1} biodiesel	3
Glycerol	g kg^{-1} treated oil	50
Electricity	kWh t^{-1} biodiesel	420
Steam	MJ t^{-1} biodiesel	31
Water	g kg^{-1} treated oil	23

VII. RESULTS AND DISCUSSIONS

The new Jatropha hybrid is labelled as elite because it produced the maximum possible output with the same amount of input. A huge number of Jatropha accession from 8 different Southeast Asia's countries were grown in Malaysia from cuttings. The plant was evaluated periodically for 1 year to collect data related to plant growth and yield. After 1 year, data were analyzed and accessions with highest traits value are selected as parent for hybridization in order to produce new hybrid that possess highest traits value and produce higher yield. It was reported that the elite hybrid of *Jatropha* can produce a maximum of 70 seeds per tree with weight of 80 kg per 100 seeds. Estimated that new *Jatropha* hybrid can produce 11.3 t/ha of dry seeds compared conventional Jatropha yield only 2-5 t/ha. Energy analysis of biodiesel production from elite Jatropha in Malaysia is shown in table 6.

Table. 6 Energy balance for the production of 1kg biodiesel from elite Jatropha hybrid in Malaysia

Item	MJ/kg	
Fertilizers	6.54	
Herbicides	0.43	
Transportation	0.09	
Diesel consumption	1.28	
Electricity (oil extraction)	2.94	
Methanol	8.22	
Sulphuric acid	0.05	
NaOH	0.21	
Electricity (transesterification)	5.45	
Steam	0.03	
Briquette as solid fuel	- 9.60	
Glycerin produced	- 1.24	
Total energy input	**25.32**	
Energy output	**41.2**	
NEB	**15.88**	**26.72**
NER	**1.63**	**2.84**
	(without by-product)	**(with by-product)**

By conducting life cycle energy analysis, the new hybrid consumed 25.32 MJ of energy to produce 1 kg of biodiesel. As expected, biodiesel conversion contributes most of energy consumption with share of 55.4%. Even though *Jatropha* cultivation of new hybrid in Malaysia requires high fertilizer application, the total of energy consumed in agricultural process is only 28.5% of total energy used. In biodiesel production from *Jatropha*, transportation is the lowest energy required process with only 4.5%. In addition, utilization of by-product from the process can generate about 10.8 MJ/kg of biodiesel produce. Most of it coming from briquette used as fuel for the boiler.

By considering the biodiesel energy factor of 41.2 MJ/kg, life cycle analysis results in NEB of 15.89 MJ/kg when no by-product is utilized compared to 26.72 MJ/kg for using briquette as boiler fuel. As for NER the value increase from 1.63 to 2.84 when the by-products are utilized as fuel for biodiesel conversion process. Both NEB and NER values indicate that production of biodiesel from new *Jatropha* hybrid results in energy gain that have the potential to be a feasible biofuel feedstock. The analysis shows significant increase in energy performance when seed briquette is used as solid fuel in boiler. However, more detail studies are required to justify the feasibility of *Jatropha* as biodiesel feedstock due to high fertilizer and methanol consumption might lead to higher emissions when compared with conventional diesel.

VIII. CONCLUSIONS

Biodiesel is considered as the most promising candidate to reduce the word's dependency on fossil fuel, while contributing to the collective effort in reducing the global emissions of the greenhouse gases. However, the choice of feedstock for biodiesel production plays is a critical factor in keeping the cost low. One of the ways to achieve this is by having high yield elite *Jatropha curcas* hybrid planted in Malaysia for the purpose of producing biodiesel. From the life cycle energy analysis done, the new hybrid consumed 25.32 MJ of energy in order to produce 1 kg of biodiesel, where most of the energy is needed in the biodiesel conversion process. When by-products are further used as fuel, significant improvement can be seen in both values of NEB and NER, amounting to 26.72 MJ/kg and 2.84, respectively. Nevertheless, the feasibility of this elite hybrid to be used as feedstock for biodiesel production needs to be further investigated due to the high usage of components such as fertilizer and methanol.

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