Renewability Assessment of Kamani (*Calophyllum inophyllum*) Biodiesel in Indonesia

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Abstract: Kamani or *Calophyllum inophyllum* is a non-edible seed which has potential to be a feedstock for biodiesel. Kamani trees are mostly found around coastal areas and are also known as forest trees. Kamani seed can be a promising alternative feedstock due to its high oil yield, simple cultivation procedure and non-edible seeds whereas palm oil which is currently used as biodiesel feedstock has environmental concerns and it is also produced for food thus raising issues about food versus fuel. The analysis of the energy inputs and outputs from kamani biodiesel show that its production is efficient because energy from output is higher than the input. Kamani biodiesel can also be considered renewable because its renewability factor at 1.95 (kamani biodiesel only) and 4.43 (all products) are substantially higher than 1.

Keywords: kamani; biodiesel; net energy balance (NEB); renewability factor.

1. Introduction

Limitation of fossil fuel and its increased consumption has led to numerous research projects on alternative fuels in order to find the substitute. This study focuses on biodiesel production from kamani (*Calophyllum inophyllum*). A more common plant for biodiesel is jatropha but the utilization of jatropha oil as biodiesel feedstock is still problematic due to its low productivity. The other common oil plant is palm which is one of the most efficient oil bearing crops in terms of oil yield, land utilization, efficiency and productivity. However, competition between edible oil sources as food with fuel makes edible oil not an ideal feedstock for biodiesel production. Kamani is one of potential oil plants for biodiesel feedstock. Kamani or *Calophyllum inophyllum*, is a non-edible oilseed ornamental evergreen tree belonging to the Clusiaceae family. The scientific name of "Calophyllum" comes from the Greek word for "beautiful leaf". It grows along coastal areas and adjacent lowland forests, although it occasionally occurs inland at higher elevations. It is native to eastern Africa, southern coastal India, Southeast Asia, Australia and the South Pacific. *Calophyllum inophyllum* is also often called as 'Alexandrian Laurel' in English [1].

Calophyllum inophyllum is a medium and large-sized evergreen sub-maritime tree that averages 8–20 m (25–65 ft) in height with a broad spreading crown of irregular branches. It has elliptical, shiny and tough leaves. The flower is around 25mm wide and occurs in racemose or paniculate inflorescences consisting of 4–15 flowers. The fruit (ballnut) is a round, green drupe reaching 2–4 cm (0.8–1.6 in.) in diameter and having a single large seed. When it is ripe, the fruit is wrinkled and its colour varies from yellow to brownish-red. The grey, ligneous and rather soft nut contains a pale yellow kernel, which is odourless when fresh. Calophyllum inophyllum kernels have very high oil content (75%) and the oil contains approximately 71% of unsaturated fatty acids (essentially oleic and linoloeic acids) [2].

The energy balance can be analyzed by using the net energy ratio. Net energy ratio is ratio of total energy outputs to total energy inputs, and reflects the energy efficiency of the process [3]. The renewability factor is the ratio of net bioenergy outputs to net fossil energy inputs. Net energy ratio and renewability factor are two indicators to identify net energy efficiency and net replaced fossil energy of biofuels. Renewability factor is the ratio of net bioenergy outputs to net fossil energy inputs. Renewability >1 is a minimum requirement to indicate that the biofuel system can help reduce dependency of fossil-based fuel energy [4].

2. Methods

2.1 Goal and scope definition

The study was conducted by using life cycle approach to evaluate all energy inputs and outputs for the whole life cycle of biodiesel from kamani (*Calophyllum inophyllum*).

2.1.1 Goal definition

The aim of this study is to investigate whether kamani biodiesel is a feasible substitute for fossil diesel by obtaining its renewability factor. The information will be useful for energy policy makers, so that kamani biodiesel can be considered as a promising alternative fuel from non-edible oil plant. This study analyzed energy balance of kamani biodiesel which entails estimation of the energy consumption over the life cycle of biodiesel production, energy output from biodiesel itself and kamani oil co-products. By obtaining the energy inputs and outputs from kamani biodiesel production, the renewability factor can also be obtained.

2.1.2 Scope definition

The system boundary of this study is a life cycle of kamani biodiesel which includes kamani cultivation, kamani oil extraction and biodiesel production. The diagram of system boundary is shown in Figure 1.

The functional unit of this study is 1 ton kamani biodiesel. Hence, the energy analysis was calculated based on the functional unit that was in MJ/ton kamani biodiesel.

2.1.3 Inventory

The data quality requirements depend on the geographic area, unit processes, technology coverage, etc. In this study, data is collected from the field study and interviews, while the literature and reports as secondary sources.

Data of kamani cultivation are obtained from the owner of private kamani plantation and Forestry Service of Cilacap (Dinas Kehutanan Cilacap). All kamani cultivation is assessed, including planting, post planting, and harvesting. Data of biodiesel conversion is obtained from Koperasi Jarak Lestari which is located in Cilacap, Central Java. The data in this study includes material, energy input and output, as well as the usage of equipments.

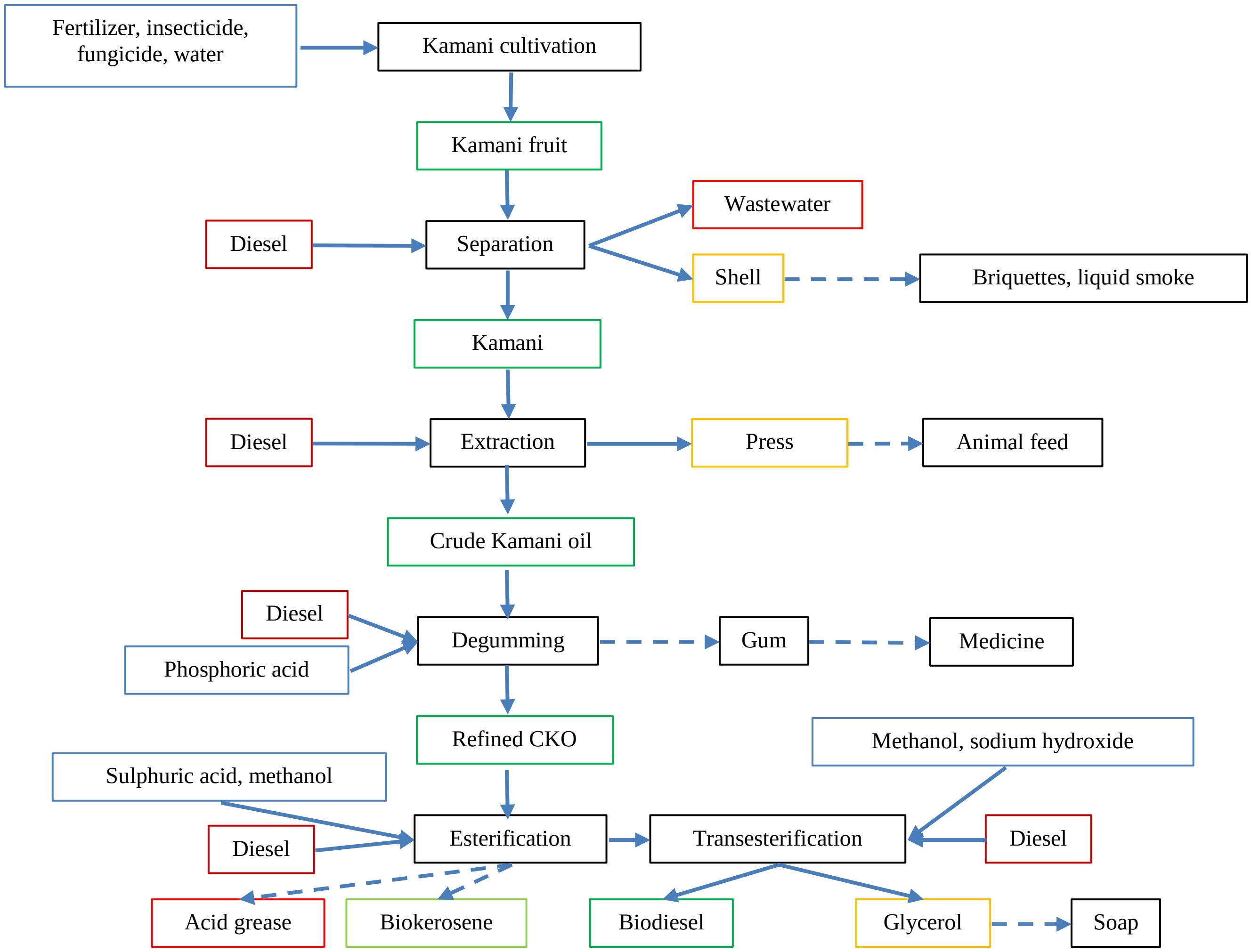

Figure 1. System boundary of kamani biodiesel.

2.2 Life cycle of Kamani Biodiesel

2.2.1 Kamani cultivation

Growing kamani tree is quite simple because it can grow by itself even without treatment but to have a large harvest, some treatment is needed. This tree can be easily found around coastal areas. Kamani can be cultivated by two methods which are generative (seed) and vegetative (macro and micro). Generative growth can be conducted with mature seed and kamani tree will produce fruit around 7 years after planting. Before planting kamani tree on land, a seed is planted in a bag and usual treatment like watering or applying fertilizer, and fungicide is carried out. After six months, the kamani tree is ready to be planted on land. The average yield per tree per year is 15 kg fresh fruit and the economic life is 25 years. The tree density per hectare is around 400 trees and higher fruit yield can be achieved by lessening the tree density.

2.2.2 Kamani oil extraction

There are some preparation should be conducted before extracting the seed, seed is needed to be separated from its shell by crusher machine. After separation, steaming and drying process, the dry kamani seeds are ready for oil extraction. The mass of dry kamani seed is half of the fresh fruit. The ready wet seed is pressed by machine to get the crude kamani oil which is then filtered. The density of kamani oil is 0.92 kg/liter. Because in kamani crude oil there is gum, degumming process should be done to remove the gum by adding phosphoric acid. The output of this process is refined kamani crude oil.

2.2.3 Kamani biodiesel production

To produce 1 ton of kamani biodiesel, about 7,448 kg of kamani fresh fruit is needed. In fact, since free fatty acid (FFA) of kamani oil is quite high (around 20%), esterification should be conducted before transesterification process. The materials used in the esterification process are 20% methanol (6.6 kg) and 2% sulfuric acid (0.66 kg). To continue the process to get kamani biodiesel, the next step is transesterification which uses 20% methanol (6.6 kg) and 1% sodium hydroxide (0.33 kg). Biokerosene can also be produced from the esterification process by washing and drying after esterification process is finished. But this study is focused on the production of kamani biodiesel; hence the process is not terminated at esterification to produce biokerosene, but continued further to transesterification. The outputs of this whole process are kamani biodiesel which is the main product and some other co-products like glycerol, shell, and press cake. Glycerol production is one-third of produced biodiesel and used for soap and cosmetics, whereas shell and press cake can be used again for energy. Press cake can be used for briquettes and in this process shells are burnt for steaming the seed.

3. Results and Discussion

The location of the study is in in Kroya, Cilacap, Indonesia. In Cilacap there are about 350 hectares of kamani plantation which are partly private and partly owned by the government. The biodiesel plant produces 300 liter of crude oil

Table 1. Energy inputs and ouputs of kamani biodiesel.

INPUT					Energy Factor [Source]
Kamani Cultivation	**Amount**	**Unit**	**Energy**	**Unit**	
NPK Fertilizer	3.81	kg	40.68	MJ	10.6 MJ/kg [6]
Fungicide	0.0004	kg	0.04	MJ	92 MJ/kg [7]
Diesel in transportation	0.033	L	1.47	MJ	44.6 MJ/L [3]
Energy input for kamani cultivation			**42.19**	**MJ**	
Kamani Oil Production	**Amount**	**Unit**	**Energy**	**Unit**	
Phosphoric Acid	0.20	kg	6.48	MJ	32.6 MJ/kg [6]
Diesel for machine	1.11	L	50	MJ	44.6 MJ/L [3]
Energy input for kamani crude oil production			**56.48**	MJ	
Biodiesel Production	**Amount**	**Unit**	**Energy**	**Unit**	
Methanol	7.94	kg	240	MJ	30.27 MJ/kg [6]
Sodium hydroxide	0.20	kg	4	MJ	18 MJ/kg [6]
Sulfuric acid	0.40	kg	6	MJ	15 MJ/kg [6]
Diesel for machine	0.65	L	29	MJ	44.6 MJ/L [3]
Energy input for kamani biodiesel production			**279**	**MJ**	
TOTAL ENERGY INPUT			**377**	**MJ/tree**	
			7,493	**MJ/ ton KB**	
OUTPUT					**Energy Factor Source**
Item	**Amount**	**Unit**	**Energy**	**Unit**	
Kamani Biodiesel (KB)	50.35	kg	2,084	MJ	41.4 MJ/kg [5]
Glycerol	16.78	kg	319	MJ	19 MJ/kg [3]
Press cake	90.00	kg	2,339	MJ	25.9 MJ/kg [8]
TOTAL ENERGY OUTPUT			**4,742**	**MJ/ tree**	
			94,182	**MJ/ ton KB**	

Table 2. Comparison between Kamani, Palm and Jatropha.

	Kamani [9]	Palm [10]	Jatropha [6, 11]
Oil yield	1,375 kg oil/ha/year	3,500 kg oil/ha/year	400 - 500 kg oil/ha/year
Oil content	40 - 45%	40 - 50%	17.7 - 25.1 %
Trees per hectare	400 trees	140 trees	1,667trees
Minimum plantation time	7 years	3 years	5 years

per day and the maximum capacity of equipment for processing crude oil is 800 liter. In this whole production process of kamani biodiesel, fossil diesel is used for machine and transporting the fruit from fruit collector to plant. For transportation, diesel as fuel with net heating value is 44.66 MJ/kg [3] and for kamani biodiesel is 41.4 MJ/kg [5]. The distance between fruit collector place and plant is approximately 10 km and 1 ton of fresh fruit is carried per trip. This means in this case, to transport the amount of fresh fruit needed for 1 ton kamani biodiesel, the transporting should be done eight times. Other diesel consumption is in the fruit separation and pressing process, to run the machine for crushing the fruit for separation process which needs 2 liters diesel per 184 kg crude oil whereas the seed pressing process consumes five times as much fossil diesel. The energy analysis calculation of this study used a single tree as a reference flow; thus the input and output of kamani biodiesel was obtained for one tree for its economic life of 25 years. The amount of fruits per tree for 25 years economic life is 375 kg. The final calculation of energy analysis, however, is still based on the functional unit of this study which is 1 ton of kamani biodiesel which requires 7,448 kg fruit. Energy factors used in this calculation are the calorific values of the respective materials or products. The calculation result for inputs and outputs of kamani biodiesel are shown in Table 1.

Total energy output for whole life cycle of kamani biodiesel is 94,183 MJ per ton kamani biodiesel which is from,

$$Total\ energy\ output = 4{,}742\ \frac{MJ}{tree} \times \frac{7{,}448\ \frac{kg\ fruit}{ton\ biodiesel}}{375\ \frac{kg\ fruit}{tree}}$$

$$= 94{,}182\ \frac{MJ}{ton\ biodiesel}$$

The outputs of this whole process are kamani biodiesel which is the main product and some other co-products like glycerol, shell, and press cake. Glycerol production is one-third of produced biodiesel and can be used for soap and cosmetics, whereas shell and press cake can be used for energy. Press cake can be used for briquette and in this process shells are burnt for steaming the seed.

Table 2 shows the comparison between kamani, palm and jatropha related to its cultivation and oil yield. Kamani has lower oil yield than palm, but higher than jatropha. Energy analysis of biodiesel from palm oil was conducted by Pleanjai and Gheewala, the study also compared net energy balance per hectare of palm biodiesel to other various feedstocks, including Jatropha. From that study, net energy balance of Jatropha biodiesel is 11,800 MJ/ha/year (with co-products) where palm biodiesel is 3,034 MJ/ha/year (with co-products) and 2,220 MJ/ha/year (without co-products) [6]. Kamani biodiesel has net energy balance of 4,676 MJ/ha/year (with co-products) and 2,055 MJ/ha/year (without co-products).

5. Conclusion

The highest energy consumption from the whole life cycle biodiesel was from biodiesel production because of the use of methanol. Nevertheless, the energy output of kamani biodiesel is higher than the input therefore it shows that the process is efficient, the difference between output and input with co-products is 86,811 MJ/ton biodiesel and without co-products is 33,897 MJ/ton biodiesel, also referred to as the net energy balance (NEB). To know whether kamani biodiesel can be considered as a suitable substitute for fossil fuel can be seen from its renewability factor. The renewability factor should higher than 1; in this case for kamani biodiesel, the factor is 5.52 (kamani biodiesel only) and 12.57 (all products), this value indicates that kamani biodiesel is renewable and can help reducing dependence on fossil fuels.

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