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Life cycle energy analysis of biodiesel from Kamani (*Calophyllum inophyllum*)

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Abstract:
Kamani or Callophyllum inphyllum 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 8.73 is substantially higher than 1.

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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 (Friday and Okano, 2006).

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.

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 (Prueksakorn and Gheewala, 2008). 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. (Silalertruksa and Gheewala, 2009).

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.

The study was conducted by using life cycle approach to evaluate all inputs and outputs for the

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whole life cycle life of biodiesel from kamani (*Calophyllum inophyllum*) and 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 per day and the maximum capacity of equipment for processing crude oil is 800 liter. The system boundary of this study is shown in Figure 1.

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. Before planting kamani tree on land, a seed is planted in a bag and usual treatment like watering or applying fertilizer, fungicide and insecticide is carried out. After six months, the kamani tree is ready to be planted on land.

To produce 1 ton of kamani biodiesel, about 7993 kg of kamani fresh fruit is needed. After separation, steaming and drying process, the dry kamani seeds are ready for oil extraction. The mass of dry kamani seed is half that 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. 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 esterification process are 20% methanol and 2% sulfuric acid. To continue the process to get kamani biodiesel, the next step is transesterification which uses 20% methanol and 1% sodium hydroxide. 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.

The yield per tree per year is 15 kg fresh fruit and the economic life is 15 years. The tree density per hectare is around 400 trees and higher fruit yield can be achieved by lessening the tree density. 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. 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 (Prueksakorn and Gheewala, 2008) and for kamani biodiesel is 41.39 MJ/kg (Rahman et al, 2013). 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 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 is 39326 MJ, 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 8.73 and this value indicates that kamani biodiesel is renewable and can help reducing dependence on fossil

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fuels. The data of energy inputs and outputs are shown in Table 1.
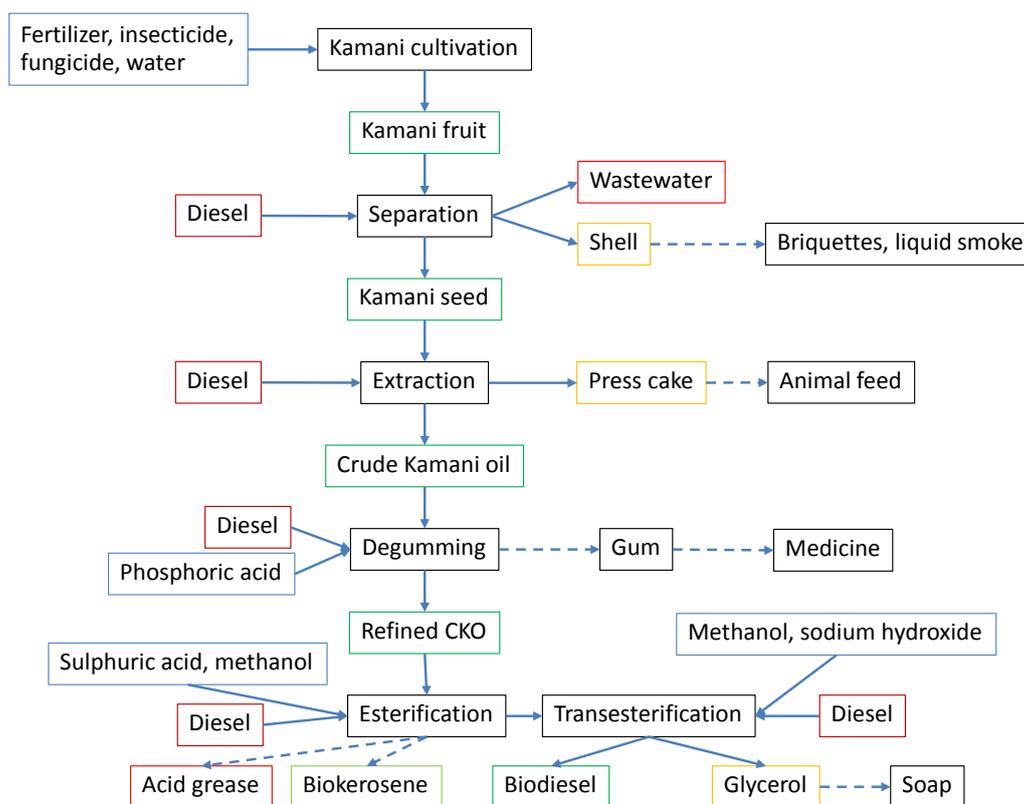
Fig. 1 System boundary of kamani biodiesel

Table 1 Energy inputs and ouputs of kamani biodiesel

INPUT				
Kamani Plantation	**Amount**	**Unit**	**Energy**	**Unit**
NPK Fertilizer	6.357	kg	67.81	MJ
Fungcide	0.001	kg	0.06	MJ
Insecticide	0.001	kg	0.13	MJ
Diesel in transportation	0.059	L	2.63	MJ
Sub-total			**70.64**	**MJ**
Kamani Oil Production	**Amount**	**Unit**	**Energy**	**Unit**
Phosphoric Acid	0.33	kg	10.80	MJ
Diesel for machine	1.99	L	88.82	MJ
Sub-total			**99.62**	MJ
Biodiesel Production	**Amount**	**Unit**	**Energy**	**Unit**
Methanol	13.24	kg	400.85	MJ
Sodium hydroxide	0.33	kg	5.96	MJ
Sulfuric acid	0.66	kg	9.93	MJ
Diesel for machine	1.16	L	51.74	MJ
Sub-total			**468.48**	**MJ**
TOTAL			**638.74**	**MJ/tree**
			22691	**MJ/ ton KB**

OUTPUT				
Item	**Amount**	**Unit**	**Energy**	**Unit**
Kamani Biodiesel (KB)	30.21	kg	1250.18	MJ
Glycerol	10.07	kg	191.30	MJ
Press cake	53.53	kg	1391.27	MJ
TOTAL			**2832.75**	**MJ/ tree**
			100635	**MJ/ ton KB**

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