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A Comparison of Life Cycle Assessment on Oil Palm (*Elaeis guineensis* Jacq.) and Physic nut (*Jatropha curcas* Linn.) as Feedstock for Biodiesel Production in Indonesia

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Abstract

The objective of this study was to perform and compare LCA of biodiesel production from crude palm oil and crude *Jatropha curcas* oil. The system boundary for LCA study from cradle to gate. The produced palm oil biodiesel has higher GWP value than *Jatropha curcas* biodiesel. Utilization of agrochemical, in form of fertilizer and plant protection, generate significant contribution to environmental impact of biodiesel production i.e. 50.46 % and 33.51 % for palm oil and *Jatropha curcas* oil, respectively. GWP emission up to five years of plantation is 1 695.36 kg-CO_2eq./t-BDF and 740.90 kg-CO_2eq./t-BDF for palm oil and *Jatropha curcas*, respectively. After production stabilised, CO_2 emission of diesel fuel decreases up to 37.83 % and 63.61 % for BDF-CPO and BDF-CJCO, respectively.

Keywords: Crude palm oil, crude *Jatropha curcas* oil, life cycle assessment, biodiesel fuel, *Elaeis guineensis* Jacq.

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Nomenclature

BDF	biodiesel fuel	**LCA**	life cycle assessment
CPO	crude palm oil	**LCI**	life cycle inventory
CJCO	crude *Jatropha curcas* oil	**LCIA**	life cycle impact assessment
FU	functional unit	**L**	litre
FFA	free fatty acid	**mo**	month
GWP	global warming potential	**t**	ton, 1 t = 10^3 kg
GHG	green house gas	**y**	year

1. Introduction

As an agrarian country and the world's largest producer of palm oil, Indonesia has huge potential to utilize renewable energy as their energy resource, particularly biodiesel. Energy security is a very important condition to be taken into consideration for any country, including Indonesia. This condition is important to ascertain a sustainable development. Although biodiesel is claimed as a renewable energy, along the process chain it often uses agrochemical materials and other non-renewable resources. This condition may resulted in pollution during biodiesel production process.

Life cycle assessment (LCA) is a systematic tool to assess the environmental impacts associated with any products, processes and activities [1,2], which is standardized in ISO 14000 series. Life cycle inventory (LCI) is one of the four steps in the LCA, which plays a very important role in conducting the assessment. The result of LCA is highly influenced by the reliability and sufficiency of data inventory of the assessed object. In Indonesia case, data accessibility which will be used in LCA is still very limited. Data collection process is the main focus in inventory analysis and the most time-consuming process of all LCA process [3]. A number of LCA studies on biodiesel production using feedstock from Indonesia has been conducted. However, results discrepancy generated in the studies are due to inconsistency of the data used. With regard to this, continuous studies are still needed to identify and approach existing condition of palm oil and jatropha curcas plantation in Indonesia.

The main feedstock for biodiesel production in Indonesia is oil palm (*Elaeis guineensis* Jacq.*)*, since Indonesia is the main producer of palm oil in the world. However, the Indonesian government has identified that physic nut can be utilized for biodiesel feedstock as well. Physic nut (*Jatropha curcas* Linn.) is a non-edible industrial crop for biodiesel fuel production. As such, it is considered as an alternative source of energy or fuel [4]. Although edible oil crops are the main feedstock for biodiesel fuel, the possibility of non-edible crops should be further investigated to avoid conflicts between crops utilization for food or biodiesel fuel. The objective of this study is to perform and compare life cycle assessment of biodiesel production from crude palm oil (CPO) and crude *Jatropha curcas* oil (CJCO).

2. Material and method

The system boundary for LCA study is shown in Figure 1, where cradle to gate consists of eight sub-processes. The functional unit (FU) of this study is one ton of biodiesel fuel (BDF) production from *Jatropha curcas* and oil palm. Indonesia consists of numerous islands, such as Sumatra, Java, Kalimantan, Sulawesi, and Papua which have different characteristics of soil, climate, and other factors which need different treatment. Data that were obtained in this study particularly concerns for Java condition. LCI analysis was performed based on data collected from palm oil plantation in *PTPN VIII Unit Kebun Kertajaya Lebak Banten*. While, data for *Jatropha curcas* plantation, harvesting and oil extraction were collected from jatropha curcas centre *Pakuwon Sukabumi* West Java, and other relevant sources, as well as laboratory measurement.

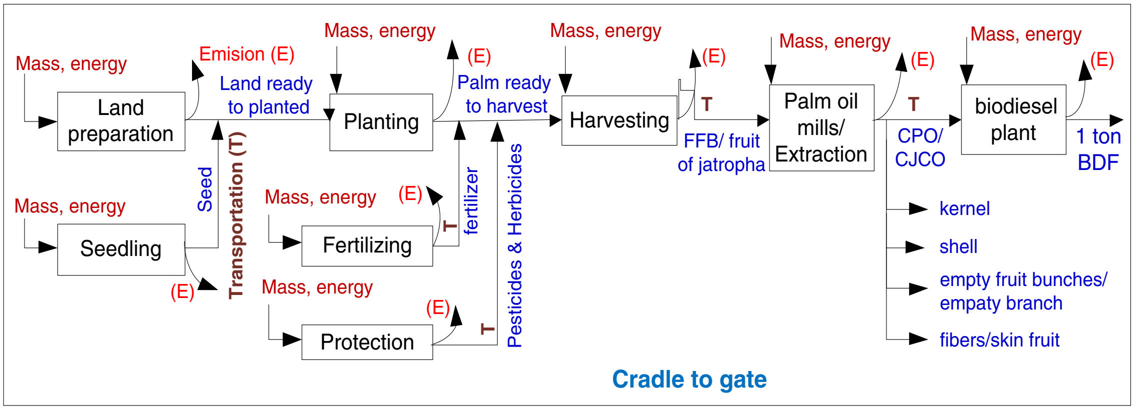


Fig.1. The system boundary of this study

Life cycle inventory analysis was performed on the material and energy inputs, air emission, waterborne emission, and solid wastes involved in biodiesel production. Each stage of analysis and calculations was carried out before and after plants yield. Based on field survey, it can be assumed that oil palm and *Jatropha curcas* will have stable productivity from the 5th y onward. The first production of oil palm occurs at 30 mo old while *Jatropha curcas* at 4 mo.

Transportation from seedling to plantation area, plantation to palm oil mills, palm oil mills to biodiesel plant was also considered in this study. The distance of transportation (a central point at the palm oil mills at *Kertajaya Lebak Banten* and central of *Jatropha curcas* center *Pakuwon Sukabumi*), the capacity and diesel fuel ratio of each path are as follow: i) from nurseries to land: 30 km, 5 t per truck, 1: 5 (1 L for 5 km); ii) from harvesting to palm oil mills: 150 km, 10 t per truck, 1: 7; iii) from palm oil mils to biodiesel mill (at *Bekasi*): 200 km, 10 t per truck.

3. Result and discussion

3.1. Life cycle inventory

The result analysis of LCI consists of input-output mass and energy as shown in Figure 1. The description of eight sub-processes involved in LCI for oil palm and *Jatropha curcas* is shown in Table 1. Comparison of material and energy used for one t production of oil palm and *Jatropha curcas*-based biodisel feedstock is shown in Table 2 [5-11]. Stable productivity of oil palm at *PTPN VIII* is approximately at 21.5 t ha^{-1} for Dura, Tenera, Pisifera varieties, etc. [6,7,10], while *Jatropha curcas* has stable productivity at about eight t ha^{-1} for IP3-P [5,9]. Production amount of biodiesel from palm oil and *Jatropha curcas* oil during its life cycle (25 y) is shown in Figure 2. From this figure it can be seen that stable productivity of each crops will be obtained at the 5th y.

The fact shows that weeds population in oil palm estate grow higher than *Jatropha curcas* trees. In order to control the weeds, some efforts are spent. That is why during land preparation, palm oil requires higher herbicide than *Jatropha curcas* (Table 2). The weeds grow around palm seedlings to as high as 1.5 m, while *Jatropha curcas* tree height is approx. 0.5 m. Oil palm plants also needs more diesel fuel than jatropha curcas. This condition is resulted from the need to mechanically tillaging the soil around palm oil plants to make the plants grow well, whereas that need doesn't exist for the *Jatropha curcas* which grow well under critical environmental condition.

At nursery stage, oil palm uses higher amount of pesticides and fertilizer rather than jatropha curcas. This condition is due to long process of oil palm seedlings (about 12 mo) compared to *Jatropha curcas*'s three months. Oil palm seedlings' stage process consists of growth stage of seedlings and seedling nursery preliminary which need intensive amount of fertilizers and pesticides. During the fertilizing phase at planting sub-process, *Jatropha curcas* needs higher amount of fertilizer compared to oil palm. As both plants need fertilizer to be put into the planting holes just before planting, the higher fertilizer needs for *Jatropha curcas* is due to greater number of plants per hectare in jatropha (around 2 500 trees) compared to oil palm (about 136 trees) [5,7,9,11].

Table 1. The comparison of biodiesel production from CPO and CJCO with boundary cradle to gate

Input activities	Component	Oil palm	*Jatropha curcas*
(1) Land preparation	Early land uses	Prime forest	Coarse grass forest
	Soil fertility	Fertile	Less fertile
	Tree, diameter > 60 cm	26 to100 trees ha^{-1}	No trees
	Tree, diameter > 30 cm	Approx. 2 500 trees ha^{-1}	Approx. 500 trees ha^{-1}
	Coarse grass	(10 to 30) groups m^{-2}	(10 to 30) groups m^{-2}
	Soil tillage	Effective soil depth (50 to 150) cm	Effective soil depth (20 to 30) cm
	Plant above the soil surface	Nuts	No plants, usually
(2) Seedling	Seedling time	12 mo	3 mo
	Seedling source	Seed	Seed, steck
(3) Planting	Plants width space	9 m × 9 m × 9 m	2 m × 2 m × 2 m
	Number of plants	136 ha^{-1}	2 500 ha^{-1}
	Number of hole	50 cm × 40 cm × 40 cm	40 cm × 40 cm × 40 cm
(4) Fertilizing	Fertilizer compound	N,P,K,Mg,B, organic fertilizer	N,P,K, organic fertilizer
	Intensity	Very intensive	Scarcely conducted
(5) Protection	Plant pest	Many kinds of pest presents	Almost not present
(6) Harvesting	Start to produce	30 mo	4 mo
	Production on stable productivity	8 t.seed ha^{-1}	21.5 t.FFB ha^{-1}
	Edible/non-edible	Edible	Non-edible
(7) Palm oil mills or Extraction oil	Production of crude oil	By milling	By extraction
	Value of FFA	< 2	> 2
	Produced biomass	Empty bunch, fruit fiber, shell, palm kernel	Kernel pulp, shell, jatropha oil cake
(8) Biodiesel production	Reaction of biodiesel production	Transesterification	Esterification and transesterification
	Ratio of crude oil to BDF	92 %	91 %
	Biodiesel source	Pulp, kernel	Kernel
	Catalyst	Alkali	Acid and alkali

Based on the fertilizing sub-process stage (Table 2) it can be seen that the material and energy utilization for palm oil are higher than *Jatropha curcas* due to indigenous characteristic of oil palm. Similar to this condition, oil palm which is more susceptible to plant pest's needs higher amount of insecticides and pesticides during protection sub-process. In order to provide appropriate dose, the dose application will change continuously based on plant's needs which analyzed by soil and leaves nutrient needs. This analysis will result precise value of what amount of fertilizer needed by plant is. *Jatropha curcas* grown in Indonesia is known as poisonous plant so it has high resistance to pest and disease attack. It is probably caused by the planting system that is generally mixed with other plants such as *gamal* (*Glyrecidia sepium* Jacq.) and *waru* (*Hibiscus tiliaceus* Linn.). If planting is conducted in monoculture system with wide space to others plants it might result the occurrence of pests and diseases.

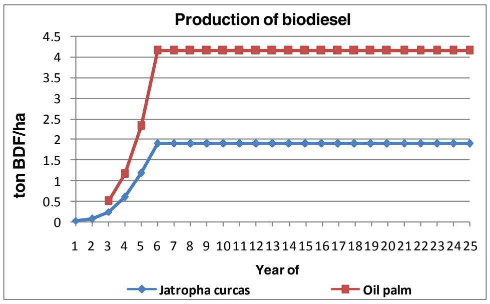


Fig.2. Productivity of biodiesel ha^{-1} for oil palm and *Jatropha curcas*

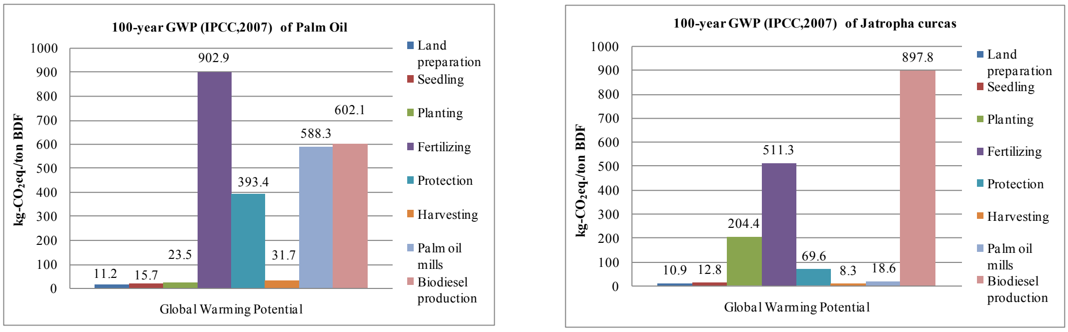
At the stage of harvesting sub-process, the transport energy uses for oil palm is higher than *Jatropha curcas* due to the differences of harvesting yield. The yield of oil palm is higher than *Jatropha curcas*. In the case of crude oil production, jatropha curcas oil needs only electricity and diesel fuel for its process. On the other hand, palm oil mills need more materials and energy. At the stage of biodesel production sub-process, due to high average value of free fatty acids (FFA) in jatropha curcas oils, it needs esterification stage before transesterification. Consequently, jatropha curcas oils needs more materials and energy.

Table 2. Materials and energy for 1 t BDF from *Jatropha curcas* and oil palm

Input activities	Input names	Unit	Oil palm	*Jatropha curcas*
	Herbicide	kg	0.86	0.63
(1) Land preparation	Diesel fuel for toppling and clearing	L	0.703	1.21
	Fungicides	kg	-	0.85
	Insecticides	kg	2.0×10^{-4}	0.006
	Chemical fertilizer Urea 0.2 %	kg	4.9×10^{-4}	-
	Organic fertilizer	kg	8.37	9.38
	Kieserite ($MgSO_4$)	kg	2.01	-
(2) Seedling	Urea	kg	7.0×10^{-5}	-
	Herbicide	kg	0.97	-
	Dolomite	kg	2.95	-
	Compound fertilizer	kg	4.69	-
	Electricity for Pump Water	kWh	0.44	-
	Pesticides	kg	0.004	-
Transportation	Diesel fuel for truck 5 t	L	1.004	1.19
	TSP/SP36	kg	13.39	79.56
(3) Planting	Organic fertilizer	kg	-	994.52
	Rock Phosphate	kg	22.39	-
	KCl	kg	-	15.91
	Compound fertilizer	kg	9.84	
	Rock Phosphate	kg	252.49	
	ZA/Urea	kg	279.46	87.52
(4) Fertilizing for five years	HGF Borate	kg	6.68	
	TSP/SP36	kg	117.14	278.47
	MOP/KCl	kg	245.99	95.47
	Kieserit	kg	184.08	
	Organic fertilizer	kg	-	994.52
	Herbicides	kg	56.317	
(5) Protection for five years	Insecticides (liquid and powder)	kg	1.323	
	Pesticides	kg	0.81	2.96
	Diesel for power sprayer and fogging	L	0.554	
(6) Harvesting (Transportation)	Diesel fuel for truck 10 t	L	5.03	2.47
	Electricity	kWh	34.39	14.83
	Steam consumption	kg	1 325.39	-
	Water consumption	m^3	3.97	-
	PAC	kg	0.13	-
	Flokulon	kg	5.0×10^{-4}	-
(7) Palm oil mills vs Oil extraction	NaOH	kg	0.107	-
	H_2SO_4/HCl	kg	0.109	-
	Tanin Consentrate	kg	0.045	-
	Poly Perse BWT 302	kg	0.045	-
	Alkaly BWT 402	kg	0.043	-
	Shell consumption	kg	133.86	-
Transportation	Diesel fuel for truck 10 t	L	2.54	1.89
(8) Biodiesel production	Methanol	t	-	0.45
Esterification	H_2SO_4	t	-	0.03
	Electricity	kWh	-	1.29
	Methanol	t	0.27	-
	Electricity	kWh	15.65	15.65
Transesterification	NaOH	t	0.08	0.08
	Water consumption	L	1 700.68	1 719.18
	Diesel fuel for Boiler	L	14.00	16.00

3.2. Life cycle impact assessment (LCIA)

LCIA was carried out using data produced in inventory analysis and MiLCA-JEMAI (Multiple Interface Life Cycle Assessment-Japan Environmental Management Association for Industry) version 1.1.2.5 for data processing. Five categories of environmental impacts are of interest, namely global warming potential (GWP), acidification, waste for landfill volume, eutrophication, and energy consumption (Table 3). Table 3 shows that total environmental impact before stable productivity period for palm oil biodiesel production is higher than jatropha curcas biodiesel production. Global warming potential is the most significant environmental impact made by biodiesel production either from palm oil or jatropha curcas oil. Most of the global warming emission emerges from utilization of agrochemical in form of fertilizer and plant protection, i.e. 50.46 % and 33.51 % for palm oil biodiesel and jatropha curcas biodiesel, respectively. Other works conducted by [12] and [13] showed that the value of GHG emission in crude jatropha curcas oil extraction process is estimated to be 1 340 kg-CO$_{2eq}$/t-CJCO and 80 kg-CO$_2$eq/t-BDF. The GWP value is 18.65 kg-CO$_2$eq./t-BDF which assume that drying is carried out naturally (sun drying).



(a) (b)

Fig.3. (a) The value of GWP until five years of oil palm; (b) The value of GWP until five years of *Jatropha curcas*

Life cycle of oil palm is about 25 y [6,7], while *Jatropha curcas* can reach up to 50 y [5,9,12]. The *Jatropha curcas*'s productivity is assumed to be stable from the 25th y on. From Figure 3(a) and Figure 3(b), it can be seen that the GWP value for oil palm is higher than *Jatropha curcas* in every stages except for planting and biodiesel production stages. The most significant environmental impact based on GWP value is caused by fertilizing and biodiesel production stages both at oil palm and *Jatropha curcas*. The total value of GWP emission before stable productivity is 2 568.82 and 1 733.67 kg-CO$_2$eq./t-BDF for oil palm and *Jatropha curcas*, respectively. Figure 3(a) shows that palm oil's GWP value of eight sub-processes which consist of land preparation, seedling, planting, fertilizing, protection, harvesting, palm oil mills, and biodiesel production is 0.44 %, 0.61 %, 0.91 %, 35.15 %, 15.31 %, 1.23 %, 22.90 %, and 23.44 %, respectively. While for *Jatropha curcas* as shown in Figure 3(b) is 0.63 %, 0.74 %, 11.79 %, 29.49 %, 4.02 %, 0.48 %, 1.08 %, and 51.78 %, respectively. Table 4 shows the proportion of each stage which comprised into pre-harvest, harvesting and post-harvest.

Lord et al. stated that environmental impact towards aquatic, land, air and others of palm oil processing from operation to processing stage i.e. 47 %, 24 %, 8 %, and 21 %, respectively [14]. Prueksakorn et al. said that the major contribution of green house gas (GHG) effect during biodiesel production from jatropha comes from the production and use of fertilizers, diesel oil consumption for irrigation, and transesterification process which is accounted by 31 %, 26 %, and 24 %, respectively [15]. Prueksakorn et al. also explained that CO$_2$ emissions for producing biodiesel from crude jatropha oil with transesterification method is generated from land preparation, cultivation, irrigation, fertilizing, cracking, extraction oil, filtering, and transesterification process which accounted by 4.7 %, 0.2 %, 26.1 %, 30.3 %, 3 %, 10.9 %, 0.5 % and 24.3 %, respectively [15]. Ndong et al. gives the details of GHG emissions in the various processes as follows: the cultivation of jatropha which accounted by 52 % of total emissions, while transesterification and combustion phase are 17 % and 16 %, respectively [16]. Large emissions occur during fertilizer application, i.e. 93 % [16].

From Figure 4(a) and Figure 4(b), it can be seen that energy consumption value for palm oil is higher than jatropha curcas in every stages except for planting and biodiesel production. The largest energy consumption for *Jatropha curcas* occurs in biodiesel production sub-process i.e. 25 623.45 MJ/t-BDF. While the largest energy consumption for palm oil is fertilizing sub-process i.e. 18 240.0 MJ/t-BDF. However, energy consumption in biodiesel production sub-process of jatropha curcas oil is higher than that of palm oil due to higher free fatty acid (FFA) which needs esterification process prior to the transesterification process. The total value of energy consumption before stable productivity for palm oil and *Jatropha curcas* is 49 831.17 and 41 730.03 MJ/t-BDF, respectively.

Table 3. Environmental impacts for producing 1 t BDF from palm oil and jatropha curcas oil

Input activities	Input names	Unit	Palm oil	*Jatropha curcas*
(1) Land Preparation	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	11.21	10.88
	Acidification, DAF(LIME,2006)	kg-SO_2e	0.02	0.017
	Waste,landfill volume(LIME,2006)	m^3	4.92×10^{-6}	5.70×10^{-6}
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	1.02×10^{-6}	1.18×10^{-6}
	Energy consumption,HHV(fossil fuel)	MJ	163.41	161.66
(2) Seedling	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	15.73	12.81
	Acidification, DAF(LIME,2006)	kg-SO_2e	0.026	0.021
	Waste,landfill volume(LIME,2006)	m^3	9.57×10^{-5}	1.62×10^{-4}
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	1.93×10^{-6}	1.34×10^{-6}
	Energy consumption,HHV(fossil fuel)	MJ	242.94	186.28
(3) Planting	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	23.46	204.38
	Acidification, DAF(LIME,2006)	kg-SO_2e	0.040	0.401
	Waste,landfill volume(LIME,2006)	m^3	3.80×10^{-4}	4.40×10^{-3}
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	2.85×10^{-6}	4.17×10^{-5}
	Energy consumption,HHV(fossil fuel)	MJ	387.40	3 394.34
(4) Fertilizing	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	902.90	511.27
	Acidification, DAF(LIME,2006)	kg-SO_2e	1.02	0.81
	Waste,landfill volume(LIME,2006)	m^3	7.10×10^{-4}	8.80×10^{-4}
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	5.80×10^{-5}	7.45×10^{-5}
	Energy consumption,HHV(fossil fuel)	MJ	18 240.00	10 841.11
(5) Protection	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	393.38	69.64
	Acidification, DAF(LIME,2006)	kg-SO_2e	0.69	0.21
	Waste,landfill volume(LIME,2006)	m^3	6.70×10^{-5}	1.10×10^{-4}
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	6.90×10^{-5}	8.93×10^{-6}
	Energy consumption,HHV(fossil fuel)	MJ	6 211.61	1 178.64
(6) Harvesting	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	31.67	8. 27
	Acidification, DAF(LIME,2006)	kg-SO_2e	0.058	0.015
	Waste,landfill volume(LIME,2006)	m^3	1.10×10^{-8}	2.86×10^{-9}
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	9.47×10^{-11}	2.47×10^{-11}
	Energy consumption,HHV(fossil fuel)	MJ	422.55	110.38
(7) Palm oil mills or Extraction oil	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	588.34	18.65
	Acidification, DAF(LIME,2006)	kg-SO_2e	0.98	0.053
	Waste,landfill volume(LIME,2006)	m^3	8.20×10^{-5}	5.24×10^{-6}
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	6.39×10^{-5}	7.49×10^{-6}
	Energy consumption,HHV(fossil fuel)	MJ	7 994.14	234.18
(8) Biodiesel production	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	602.12	897.77
	Acidification, DAF(LIME,2006)	kg-SO_2e	0.72	0.98
	Waste,landfill volume(LIME,2006)	m^3	3.07×10^{-4}	5.17×10^{-4}
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	4.73×10^{-5}	5.89×10^{-5}
	Energy consumption,HHV(fossil fuel)	MJ	16 169.11	25 623.45
Total	GWP, 100-year GWP(IPCC, 2007)	kg-CO_2e	2 568.82	1 733.67
	Acidification, DAF(LIME,2006)	kg-SO_2e	3.55	2.50
	Waste,landfill volume(LIME,2006)	m^3	9.40×10^{-4}	0.015
	Eutropication, EPMC(LIME,2006)	kg-PO_4e	2.40×10^{-5}	1.90×10^{-5}
	Energy consumption,HHV(fossil fuel)	MJ	49 831.17	41 730.03

Table 4. Percentage of GWP-100 years for LCA with boundary cradle to gate at oil palm and *Jatropha curcas*

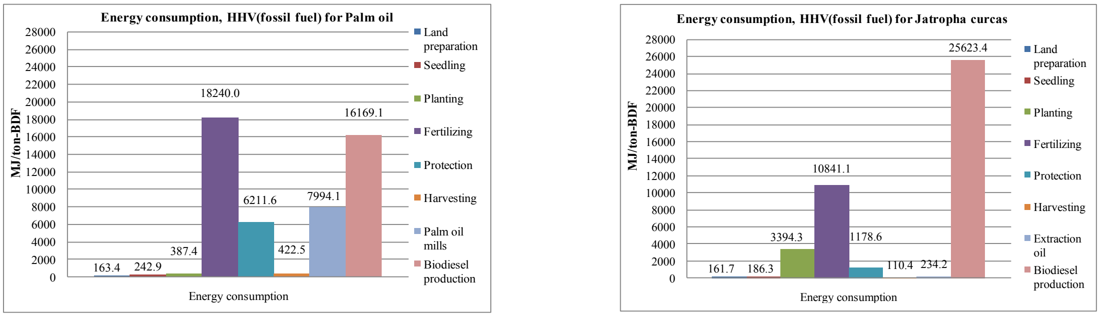
Input activities	Percentage (%)	
	Oil palm	*Jatropha curcas*
Pre-harvest	52.42	46.66
Harvesting	1.23	0.48
Post-harvest	46.34	52.86

Figure 4(a) shows that palm oil energy consumption during land preparation, seedling, planting, fertilizing, protection, harvesting, palm oil mills, and biodiesel production is 0.33 %, 0.49 %, 0.78 %, 36.60 %, 12.47 %, 0.85 %, 16.04 %, and 32.45 %, respectively. While for jatropha curcas, the value of each sub process as shown in Figure 4(b) is 0.39 %, 0.45 %, 8.13 %, 25.98 %, 2.82 %, 0.26 %, 0.56 %, and 61.4 %, respectively. Table 5 shows the proportion of each stage which comprised into pre-harvest, harvesting and post-harvest. Prueksakorn et al. also explained that energy consumption needed for transesterification is higher than fertilization [15]. On the contrary, fertilization is higher in green house gas emissions. It occurs because of N compound and the use of N_2O has strong effects on GHG.

Table 5. Percentage of energy consumption for LCA with boundary cradle to gate at oil palm and *Jatropha curcas*

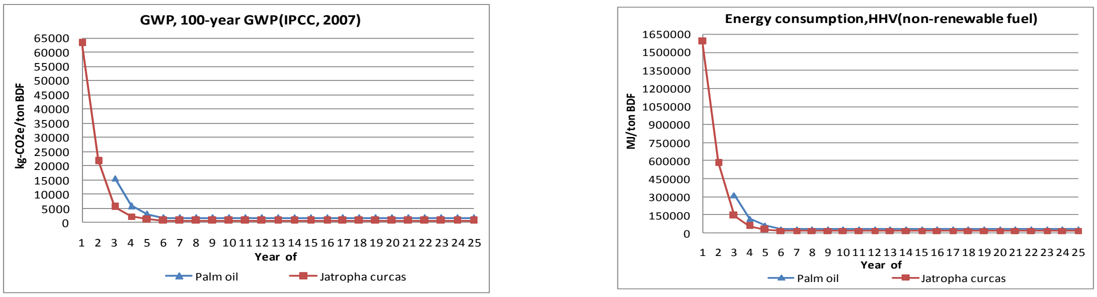
Input activities	Percentage (%)	
	Oil palm	*Jatropha curcas*
Pre-harvest	50.66	37.77
Harvesting	0.85	0.26
Post-harvest	48.49	61.96

Figure 5(a) and Figure 5(b) show that GWP emission at stable productivity (6 to 25) y is 1 658.50 and 740.90 kg-CO_2eq./t-BDF for palm oil and jatropha curcas oil, respectively. Assessment conducted by Sekiguchi [13] shows that total CO_2 emission is 460 kg-CO_2eq/t-BDF for SMV method, 790 kg-CO_2eq/t-BDF for alkali-catalyzed method and 3 400 kg-CO_2eq/t-diesel for diesel oil. The results differences might be due the difference in method and assumptions adopted in the studies. The energy consumption for fossil fuel at stable productivity is 33 190.05 and 19 395.89 MJ/t-BDF for oil palm and *Jatropha curcas*, respectively. The GWP value and energy consumption of oil palm and *Jatropha curcas* is decreasing until the 5th y and stable until 25th y. Similar trend emerges in impact assessment also occurs at acidification, eutrophication, and landfill waste as shown in Figure 6(a), Figure 6(b) and Figure 7(a), respectively.



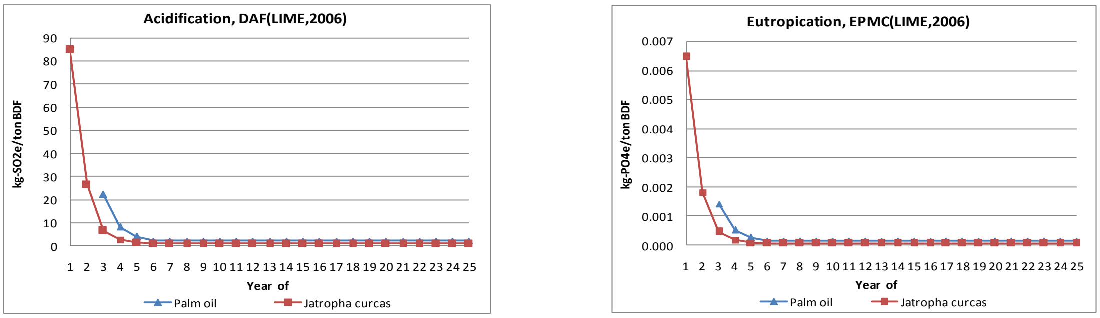
(a) (b)

Fig.4. (a) The value of energy consumption until 5 y of oil palm; (b) The value of energy consumption until 5 y of *Jatropha curcas*



(a) (b)

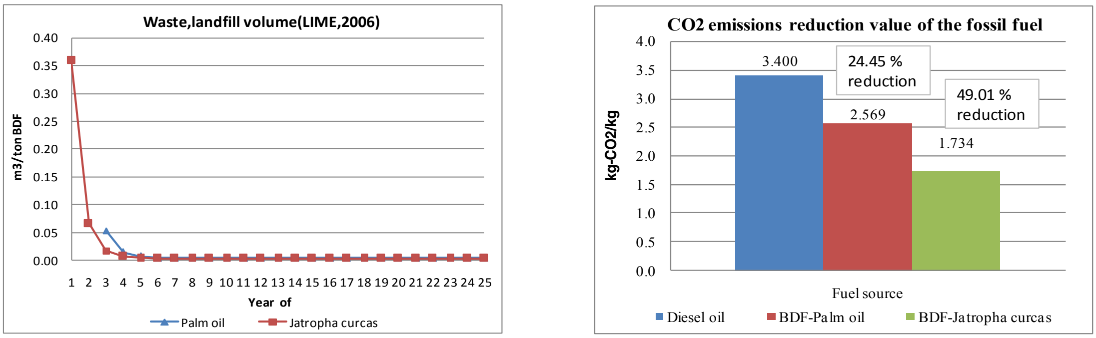
Fig.5. (a) The value of GWP for oil palm and *Jatropha curcas*; (b) The value of energy consumption for oil palm and *Jatropha curcas*



(a) (b)

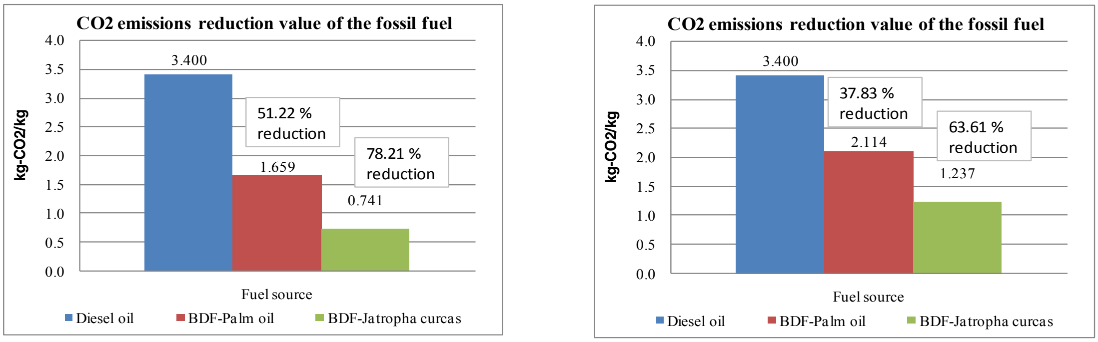
Fig.6.(a) The value of acidification for oil palm and *Jatropha curcas*; (b) The value of eutrophication for oil palm and *Jatropha curcas*

Figure 7(b), Figure 8(a) and Figure 8(b) show comparison between reduction value of CO_2 emission produced in oil palm and *Jatropha curcas* compared to diesel oil. Figure 7(b) and Figure 8(a) show that reduction in CO_2 emissions is greater at stable productivity due to lower input energy and mass which only used for maintenance, fertilizing and harvesting. Land preparation, seedling, and planting sub-process are not carried out in this phase.



(a) (b)

Fig.7. (a) The waste landfill volume for oil palm and *Jatropha curcas*; (b) The reduction value of CO_2 emission before stable productivity



(a) (b)

Fig.8. (a) The reduction value of CO_2 emission after stable productivity (6 to 25) y; (b) The total value of CO_2 emission (1 to 25) y

Figure 8(b) shows combination value of CO_2 emission before and after stable production. It can be seen that reduction value of CO_2 emissions for BDF-CPO and BDF-CJCO is 37.83 % and 63.61 %, respectively. Research conducted by Gomma et al. mentioned that biodiesel of jatropha save green house gas emission by 66 % compared with diesel fuel even it accounts pasture land use [17]. Prueksakorn et al. stated that green house gas emission is 77 % lower than production and diesel fuel consumption [15].

4. Conclusion

Total environmental impact for biodiesel production from palm oil is higher than that of jatropha curcas oil. Utilization of agrochemical in form of fertilizer and plant protection generate significant contribution to environmental impact of biodiesel production i.e. 50.46 % and 33.51 % for palm oil and jatropha curcas oil, respectively. GWPemission until five years of plantation is 1 695.36 kg-CO_2eq./t-BDF and 740.90 kg-CO_2eq./t-BDF for palm oil and jatropha curcas, respectively. After stable production, CO_2 emission of diesel fuel decreases up to 37.83 % and 63.61 % for BDF-CPO and BDF-CJCO, respectively.

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References

[1] Ciambrone DF.Environmental life cycle analysis. Florida: CRC Press LLC; 1997.

[2] Curran MA. Environmental life-cycle assessment.McGraw-Hill. New York, N.Y.; 1996.

[3] Searcy C. An introduction to life cycle assessment. [Internet] Accessed 30 July 2011 from http://www.i-clps.com/lca/; 2000

[4] Tambunan AH, Situmorang JP, Silip JJ, Joelianingsih A, Araki T. Yield and physico chemical properties of mechanically extracted crude *Jatropha curcas L.* oil. Biomass and Bioenergy 2012; 43:12-17.

[5] Ferry Y. Budidaya jarak pagar [The cultivation of *Jatropha curcas* Linn.]. Pakuwon-Sukabumi, Balai Tanaman Industri-Indonesia; 2009.[Bahasa Indonesia]

[6] Pahan I. Panduan lengkap kelapa sawit-manajemen agribisnis dari hulu hingga hilir [Complete guide oil palm-agribusiness management from up stream to downstream]. Depok : Penebar Swadaya.; 2011.[Bahasa Indonesia]

[7] Lubis RE, Widanarko A. Buku pintar kelapa sawit [Book smart oil palm]. Jakarta : Agromedia; 2011.[Bahasa Indonesia]

[8] Kamahara H, Widiyanto A, Tachibana R, et al. Improvement potential for net energy balance of biodiesel derived from palm oil : A case study from Indonesia practice and carbon footprint and life cycle assessment: Current status, action needed, and future prospect. J.Biomass and Bioenergy.Vol.34, p.1818-1824; 2010.

[9] Pranowo D. Teknologi budidaya jarak pagar [The cultivation technology of *Jatropha curcas* Linn.]. Pakuwon-Sukabumi, Balai Tanaman Industri- Indonesia; 2009.[Bahasa Indonesia]

[10] Siregar K, Tambunan AH, Irwanto AK, Wirawan SS, Araki T. A Comparison of life cycle inventory of pre-harvest, production of crude oil, and biodiesel production on *Jatropha curcas* and palm oil as a feedstock for biodiesel in Indonesia. Proceeding of Ecobalance 2012 conference,Yokohama. Japan. 21 – 24 November 2012.

[11] Tjahjana BE, Pranowo D. Budidaya dan pengolahan minyak jarak pagar [Cultivation and processing of crude jatropha curcas oil]. Pakuwon-Sukabumi, Balai Tanaman Industri-Indonesia; 2010. [Bahasa Indonesia]

[12] Pramudita D. Inventori data pascapanen dan ekstraksi minyak Jarak Pagar (*Jatropha curcas* Linn.) [Life cycle inventory analysis of postharvest handling and extraction of *Jatropha curcas* oil]. [Thesis] Bogor Agricultural University; 2011.[Bahasa Indonesia]

[13] Sekiguchi T. Life cycle assessment of biodiesel fuel production by SMV method. Workshop of life cycle assessment of biodiesel production using non-catalytic super-heated methanol vapor method, The Universuty of Tokyo and IPB. Bogor. 28 October 2011.

[14] Lord S, Clay J. Environmental impacts of oil palm-practical considerations in defining sustainability for impacts on the air. USA : Land and Water; 2009.

[15] Prueksakorn K, Gheewala SH. Energy and green house gas implications of biodiesel production from *Jatropha curcas* Linn.. The 2nd Joint International Conference on "Sustainable Energy and Environment (SEE 2006)-Bangkok. Thailand. 21-23 November 2006.

[16] Ndong R, Vignoles MM, Girons OS, Gabrielles B, Pirot R, Domergue M, Sablayrolles C. Life cycle assessment of biofuels from *Jatropha curcas* in West Africa : a field study. GCB Bioenergy 2009; 1:197-210.

[17] Gomaa M, Alimin AJ, Kamarudin KA. The effect of EGR rates on NO_x and smoke emmisions of an IDI diesel engine fuelled with jatropha biodiesel blends. International Journal of Energy and Enviroment 2011; 2(3):477-490.