Comparison of energy production, net energy balance, net energy ratio, and renewable index for biodiesel production from oil palm (*Elaeis guineensis* Jacq.) and jatropha (*Jatropha curcas* L.) based on life cycle assessment

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Abstract. Biodiesel is produced mostly from oil palm (*Elaeis guineensis* Jacq.) and jatropha (*Jatropha curcas* L.) and used intensively in Indonesia. This happened because since 2007 Indonesia has become the main palm oil producer in the world. On the other hand, jatropha is a non-edible and easy to grow industrial plant in various regions in Indonesia, which makes it a good alternative for the production of biodiesel fuel. The objective of this research is to calculate and analyze the consumption of energy production, renewable energy, non-renewable energy, fossil energy and see the relationship of net energy balance (NEB), net energy ratio (NER), and renewable index (RI) for biodiesel production from *E. guineensis* and *J. curcas* based on life cycle assessment (LCA) which reflects the condition of Indonesia. The result showed that the energy input in oil palm is higher than *J. curcas* which reflected by higher NEB and lower RI value. The NEB value of *E. guineensis* and *J. curcas* is 146 948.08 and 39 334.79, respectively. The RI value of *E. guineensis* and *J. curcas* is 0.162 and 0.270, respectively. NER value of BDF-CPO (biodiesel fuel-cude E. guineensis) and BDF-CJCO (biodiesel fuel-cude J. curcas oil) is higher than 1.

Keywords: Biofuel, energy security, free fatty acid, GHG emission, renewable energy.

1. Introduction

Energy security is a very important condition to be taken into consideration for any country, including Indonesia. In 2015, Indonesia set a target to realize 23 % of primary energy supply from modern renewable energy by 2025 [1, 2]. Biodiesel is one of the biofuels that has long been developed and will be used intensively in Indonesia. Biodiesel is produced mostly from oil palm (*Elaeis guineensis* Jacq.) and jatropha (*Jatropha curcas* L.) in Indonesia. This happened because since 2007 Indonesia has become the main palm oil producer in the world. On the other hand, jatropha is a non-edible and easy
to grow industrial plant in various regions in Indonesia, which makes it a good alternative for the
droduction of biodiesel fuel [3, 4]. The condition and energy analysis used in this study are expected to
provide more comprehensive assessment on biodiesel development. Stable productivity of E.
guineensis at PTPN VIII (Perusahaan Terbatas Perkebunan Nusantara VIII—the VIII Nusantara
Plantation Inc.) is about 21.5 t ha\(^{-1}\) [5, 6], while Jatropha has a productivity of around 8 t ha\(^{-1}\) for
IP3-P [7–9]. Siregar [10] said production amount of biodiesel from palm oil and Jatropha curcas oil
during its life cycle (6 yr to 25 yr) are 4.3 t biodiesel fuel per year and 1.7 t biodiesel fuel per year.

Life cycle assessment is a systematic tool to assess the environmental impacts associated with any
products, processes and activities [Ciambrone and Curran in 10, 11], which is standardized in ISO 14
040 series. Life cycle inventory (LCI) is a very important stage in the LCA, which plays a very
important role in conducting the assessment. The LCA results are strongly influenced by the reliability
and adequacy of the inventory of the object data being assessed. In Indonesia case, data accessibility
which will be used in LCA is still very limited. The process of data collection is the main focus in the
inventory analysis and the most time-consuming process of all LCA processes [Searcy in 9].

The life cycle inventory data that uses Indonesian data and some of calculation were carried out
manually through entering calor value (MJ kg\(^{-1}\)) and calculating the amount of the product (kg) used
at each sub process of life cycle into developed mathematical equation. Required energy of energy
sources used at each sub process is calculated based on specific and inventory data that has been done.
From this value, the emission value can be calculated based on the emission factor published by
Intergovernmental Panel on Climate Change (IPCC) [12]. Analysis of energy consumption in this
study consisted of: the consumption amount of non-renewable energy, the consumption amount of
fossil energy, the consumption amount of renewable energy, the consumption amount of total energy,
NEB, NER, and RI.

Specifically for energy balance, related energy units should be in the same unit (kJ). It occurs by
adding all energy process sources i.e. energy from fossil fuel and energy from renewable material. In
renewable index analysis, the research also conducted differences study on energy sources of fossil
fuel and renewable material such as by product produced during E. guineensis and J. curcas
processing that can still be used as an energy sources. The objective of this research is to calculate and
analyze the consumption of energy production, renewable energy, non-renewable energy, fossil energy
and see the relationship of NEB, NER, and RI for biodiesel production from E. guineensis and
J. curcas based on life cycle assessment which reflects the condition of Indonesia.

2. Materials and methods

2.1. Materials and research boundaries

This research was used collecting data primary and secondary data from biodiesel production from
CPO and CJCO. Primary data was collected from Java, Sumatera and Kalimantan. Boundary in this
research is cradle to gate (figure 1) which consists of eight sub-process stages. Functional unit of this
study is 1 t of bio-diesel fuel (BDF) for E. guineensis and J. curcas. Flow diagram of energy balance
of biodiesel processing from CPO and CJCO is shown in figures 2 and figure 3. Wherein the biodiesel
production from CJCO must go through esterification before continuing with transesterification
because of the high free fatty acid value (FFA > 2), while the biodiesel production from CPO goes
directly through a transesterification reaction because of the low free fatty acid value (FFA < 2). This
consists of eight stages of main sub-processes as shown in figure 1 which can be described as follows:

(i) The boundary of this study is from cradle to gate, which consists of eight main sub processes
i.e. land preparation, seedling, planting, fertilization, protection, harvesting, palm oil
mills/extraction of crude oil, and biodiesel production using CPO and CJCO.

(ii) The article focuses on energy balance, the value of energy input and the value of energy
output (energy ratio).
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cradle to gate for oil palm

Figure 1. Boundary used for biodiesel production from CPO and CJCO to analysis energy consumption.

Figure 2. Flow diagram of energy balance for biodiesel processing from CPO.
2.2. Energy calculation and analysis tool

Life cycle impact assessment for energy used MiLCA-JEMAI software version 1.1.2.5 (regular license) using Indonesian data. At each stage of sub-process, the first step is to calculate the required energy at each process. Required energy can be obtained by defining the fuel consumption. For diesel used during transportation, the mass of used diesel fuel is calculated using equation 1.

\[
\text{mass of diesel} = \frac{\text{load (kg)} \times \text{distance (km)} \times \text{diesel consumption (L truck km}^{-1}) \times \text{density (kg L}^{-1})}{\text{capacity of truck (kg truck}^{-1})}
\]  

(1)

Energy requirement of fuel and electrical energy is calculated using equation 2 and equation 3.

\[
\text{energy of fuel} = \text{mass of fuel (kg)} \times \text{calor value (kJ kg}^{-1})
\]  

(2)

\[
\text{energy of electricity} = \text{set up of power (W)} \times \text{time (h)} \times \frac{1 \text{h}}{3600 \text{s}}
\]  

(3)

By using the value of energy consumption, the amount of emission compound can be calculated using equation 4.

\[
\text{emission} = f_{ij} \times e_i
\]  

(4)

Where:

- \(m_{ij}\): the mass of compound i (emission) of energy source j in process k (kg)
- \(f_{ij}\): the emission factor of substance i in condition k (kg kJ\(^{-1}\))
- \(e_i\): the energy produced from energy source j in process k (kJ)

Based on the amount of emission compound, the value of the environment potential impact can be calculated using equation 5.

\[
\text{d_{iy}} = \text{eq}_{iy} \times m_{ij}
\]  

(5)

Where:

- \(d_{iy}\): potential impact y due to emission compound i in process j (kg y eq.)
- \(eq_{iy}\): equivalence value of potential impact y due to compound i (kg y eq. kg\(^{-1}\) i)
- \(m_{ij}\): the mass of compound i (emission) of fuel j in process k (kg i)

The potential impact value and energy required by each process (energy produced by fuel) is summed to obtain the total value of the entire process, from the handling of pre-harvest, harvest and post-harvest, and until the biodiesel is produced. In this research, the concept of energy balance is that the incoming energy is equal to the amount of stored energy and energy leaving the system, i.e. equation 6.

\[
\text{Energy input} = \text{Energy stored} + \text{Energy output}
\]  

(6)
Assuming steady condition so that no energy is absorbed by the system, the above equation can be simplified into equation 7.

\[ \text{Energy}_{\text{input}} = \text{Energy}_{\text{output}} \]  \hspace{2cm} (7)

In the context of biodiesel processing which is being studied, the energy balance is as follow equation 8.

\[ \text{Energy}_{\text{input}} = \text{Energy}_{\text{process}} + \text{Energy}_{\text{output}} \]  \hspace{2cm} (8)

If input energy is described into sub system as shown in figure 2 and figure 3, the Equation 9 is as follow:

\[ \frac{\text{Energy}_{\text{input}}}{E_1} = \frac{\text{Energy}_{\text{CPO}}}{E_2} + \frac{\text{Energy}_{\text{MeOH}}}{E_3} + \frac{\text{Energy}_{\text{NaOH}}}{E_4} \]  \hspace{2cm} (9)

The energy process is performed from preparation-transesterification-washing and so on to form biodiesel \( E_{\text{pr}} \) see on equation 10.

\[ E_{\text{pr}} = \text{Energy}_{\text{fossil}} + \text{Energy}_{\text{non-fossil}} + \text{Energy}_{\text{electricity}} + \text{Energy}_{\text{mechanical}} + \text{Energy}_{\text{thermal}} \]  \hspace{2cm} (10)

The energy output consists of equation 11.

\[ \frac{\text{Energy}_{\text{output}}}{E_{\text{out}}} = \frac{\text{Energy}_{\text{biodiesel}}}{E_{\text{out_target}}} + \frac{\text{Energy}_{\text{glycerol}}}{E_{\text{out_residual}}} + \frac{\text{Energy}_{\text{MeOH_residual}}}{E_{\text{out}}} \]  \hspace{2cm} (11)

If catalyst (NaOH) can be recycled 100 % and calculated methanol is used so there is no residual methanol, the equation 12 is as follow:

\[ \text{Energy}_{\text{input}} = \text{Energy}_{\text{CPO}} \]  \hspace{2cm} (12)

The energy output is on equation 13.

\[ \text{Energy}_{\text{output}} = \text{Energy}_{\text{biodiesel}} + \text{Energy}_{\text{glycerol}} \]  \hspace{2cm} (13)

Based on the above mentioned equations, it can be described three energy parameters for biodiesel production and feasibility, i.e. equation 14, equation 15 and equation 16.

\[ \text{Net Energy Ratio (NER)} = \frac{\text{Energy}_{\text{output}}}{\text{Energy}_{\text{input}}} \]  \hspace{2cm} (14)

\[ \text{Net Energy Balance (NEB)} = \text{Energy}_{\text{output}} - \text{Energy}_{\text{process}} \]  \hspace{2cm} (15)

\[ \text{renewable Index (RI)} = \frac{\text{Energy}_{\text{renewable}}}{\text{Energy}_{\text{process}}} \leq 1 \]  \hspace{2cm} (16)

2.3. Assumptions and limitations on energy calculation analysis

Some of the assumptions used in this study are as follows: (i) transportation on seeds, FFB or jatropha seeds, as well as CPO or CJCO are calculated in this study i.e. from the nursery to the plantation area, from plantation to palm oil mill, as well as from the palm oil mill to the biodiesel plant; (ii) Transportation distance is assumed as one-way direction with a central point in the palm oil mill of Unit Kebun Kertajaya Lebak Banten and Jatropha curcas Estate Center Pakuwon Sukabumi. The distance from the nursery area to the planting area is 30 km with a capacity of 5 t trucks, with diesel fuel ratio 1:5 (1 L for 5 km); from harvesting area to palm oil mill is 150 km with capacity of 10 t per truck with diesel fuel ratio 1:7; and from the palm oil mill to the biodiesel plant (in Bekasi) is 200 km with a capacity of 10 t per truck; (iii) Material transportation such as fertilizer from stores to the plantation area is also taken into account; (iv) Palm oil mill is assumed has conduct methane capture; (v) Fuel used in the transportation is diesel fossil; (vi) Impact assessment was made and analyzed in
used this scenario, i.e.: The calculation was conducted annually, from year 1 to year 5 (before stable production) and from year 6 to year 25 (stable production). The calculation used Indonesian electrical data and calculated the transportation to transport material used from the store to the location.

3. Result and discussion
Energy plays an important role in the analysis of LCA. All sub-processes involved in a process obviously require energy to take place (see figure 1 as boundary in this research). In addition, emission of each sub-process is calculated based on the consumed energy. Most importantly, energy is the main aspects in LCA. The background is clear i.e. the issue of energy crisis which caused by the decreasing of reserved fossil fuel which have been the main energy source of human activity. How much energy is required in the process and how much the utility of renewable energy is the important aspect to be determined. A good process is a process with high efficiency and low negative effects.

The energy, in this analysis, consists of energy used during the process and energy that can be produced from waste utilization. Energy for this process includes conventional energy and renewable energy. Comparison between the amounts of renewable energy to total energy process is called renewability. Energy utilization of waste needs to be calculated in order to be used in the biodiesel production process. Waste will give a big contribution for input energy during production process.

Figure 4 and figure 5 indicates energy consumption for *E. guineensis* is higher than *J. curcas* in every stage except planting and biodiesel production. The biggest energy consumption for *J. curcas* occurs in the biodiesel production sub-process, which is 25 623.45 MJ t⁻¹ BDF. While the biggest energy consumption for oil palm is the fertilization sub-process, which is 18 240.0 MJ t⁻¹ BDF. However, energy consumption in the *J. curcas* oil biodiesel production sub-process is higher than *E. guineensis* because of the higher content of free fatty acids (FFA) which require an esterification process before the transesterification process. The total value of energy consumption before stable production for oil palm and *J. curcas* is 49 831.17 MJ t⁻¹ BDF and 41 730.03 MJ t⁻¹ BDF, respectively.

Figure 4 shows that oil palm 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 *J. curcas*, the value of each sub process is 0.39 %, 0.45 %, 8.13 %, 25.98 %, 2.82 %, 0.26 %, 0.56 %, and 61.4 % (figure 5), respectively. Table 1 shows the proportion of each stage consisting of pre-harvest, harvest and post-harvest. Pruksakorn et al. [13] also explained that energy consumption needed for transesterification is higher than fertilization. In contrast, greenhouse gas emissions are higher during the fertilization sub-process. This happens because N compounds and the use of N2O have a strong effect on GHG. James et al. [14] explained that the amount of energy required to produce biodiesel is relative to the energy content. This is due to renewable energy characteristic on the feedstock itself, such as *J. curcas* and *E. guineensis*, where the waste still can be used as a source of energy during processing and it also because most agriculture energy analyst believes that solar energy is freely provided.

Energy consumption of fossil fuel at stable production is 25 468.13 MJ t⁻¹ BDF-CPO for oil palm and 18 957.63 MJ t⁻¹ BDF-CJCO for *J. curcas*. Figure 6 shows the fossil energy consumption value for *E. guineensis* and *J. curcas* throughout its life cycle (1 yr to 25 yr). Figure 7 shows the value of non-renewable energy consumption, figure 8 shows the value of renewable energy consumption and figure 9 shows the value of the total energy consumption.

| Input activities | Percentage (%) | *E. guineensis* | *J. curcas* |
|------------------|----------------|----------------|----------|
| Pre-harvest      |                | 50.66          | 37.77    |
| Harvesting       |                | 0.85           | 0.26     |
| Post-harvest     |                | 48.49          | 61.96    |
Figure 4. The energy consumption value of *E. guineensis* before stable production (1 yr to 5 yr).

Figure 5. The energy consumption value of *J. curcas* before stable production (1 yr to 5 yr)
Figure 6. Fossil energy consumption value before and after stable production of *E. guineensis* and *J. curcas*.

Figure 7. Non-renewable energy consumption before and after stable production of *E. guineensis* and *J. curcas*. 
Figure 8. Total renewable energy consumption value before and after stable production of *E. guineensis* and *J. curcas*.

Figure 9. Total energy consumption value before and after stable production of *E. guineensis* and *J. curcas*.

Figure 10 shows the NEB value of BDF-CPO and BDF-CJCO throughout its life cycle. NEB value is the result of output energy values subtracted by energy processes. The output energy consists of BDF-CPO energy added with glycerol energy, while the energy process consists of fossil energy added with renewable energy which is calculated from the beginning of the process until the biodiesel is produced in accordance with the limits in this experiment. According to the NEB value, it can be seen that the value during initial production is still negative, because the production is not as high as the energy process used. The NEB value will become positive as the production increases due to the production energy in the form of produced biodiesel has become higher than the energy process during biodiesel production. The positive value of NEB means that there is energy surplus during the
production process which presents good sustainability. In this case, based on NEB value, the sustainability of CPO based biodiesel is better than CJCO based biodiesel.

![Net Energy Balance (NEB)](image)

**Figure 10.** The NEB value of BDF-CPO and BDF-CJCO throughout its life cycle (1 yr to 25 yr).

Figure 11 shows NER value for *E. guineensis* and *J. curcas* i.e. 1.041 and 1.042, respectively. NER value is derived from the value of energy output that consists of energy BDF-CPO added with glycerol energy and divided with energy input that consists of CPO energy. It turns that NER value appears to be constant value due to increased output value will increase the input value, although the NER value can reach higher value if the produced biomass energy is calculated as output energy. The NER value of *E. guineensis* and *J. curcas* is 2.93 and 2.11, respectively. NER value of *E. guineensis* is higher than *J. curcas* as *E. guineensis* produces higher biomass. Siregar et al. (2018) said that net energy balance, net energy ratio, and renewable index was 30 MJ kWh⁻¹ electric; 0.89; 0.76 respectively. This research for biomass power plant [15].

![Net Energy Ratio (NER)](image)

**Figure 11.** The NER value of BDF-CPO and BDF-CJCO throughout its life cycle (1 yr to 25 yr).

Figure 12 shows RI value of palm oil and *J. curcas*. RI is an indicator of renewable energy amount used in the biodiesel production. If RI increases or closes to one mean that more of renewable energy used in this process. In other words, if more fossil energy used in the process means that RI value
should be increased to perform environmental friendly of biodiesel production. Figure 5.13 shows that RI value of \textit{J. curcas} is higher than the palm oil. This could be caused by lower fossil energy used by \textit{J. curcas} during its life cycle than the palm oil. Both in palm oil and \textit{J. curcas} shows that RI value from the first year till the sixth year tends to have lower value. The increasing number of oil palm and \textit{J. curcas} will increase fossil fuel consumption including the diesel fuel consumption in boiler. This condition can be anticipated by using biomass produced by biodiesel during its production in boiler.

![Renewable Index (RI)](image)

**Figure 12.** The RI value of BDF-CPO and BDF-CJCO throughout its life cycle (1 yr to 25 yr).

4. Conclusions

The conclusions that can be drawn in this research are as follows:

(i) The energy input in \textit{Elaeis guineensis} is higher than \textit{Jatropha curcas} which reflected by higher NEB (net energy balance) and lower RI (renewable index) value. The NEB value of oil palm and \textit{Jatropha curcas} is 14 948.08 and 39 334.79, respectively. The RI value of \textit{Elaeis guineensis} and \textit{Jatropha curcas} is 0.162 and 0.270, respectively.

(ii) NER (net energy ratio) value of BDF-CPO (biodiesel fuel – crude palm oil) and BDF-CJCO (biodiesel fuel – crude \textit{jatropha curcas} oil) is higher than 1.

(iii) Improving Indonesia’s power plants must consider the use of low-GHG emissions (greenhouse gases), such as biodiesel fuel.

(iv) The results of this study show that from energy consumption the source of biodiesel feedstock from CJCO is better than CPO for Indonesia.

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