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Life Cycle Assessment of Biodiesel Production from Palm Oil in Indonesia

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Abstract: The objective of this study is to investigate the environmental impacts of biodiesel production from palm oil in Indonesia using life cycle assessment methodology. The functional unit of this study is 1 ton biodiesel. The main contributor to the global warming potential is the use of fertilizers and herbicides in the plantation stage contributing 58%. Co-products from palm oil process can be used for energy in the mill. Electricity also gives high environmental impact since it is purchased from the electricity grid mix which relies mostly on coal fired power plants. The biodiesel production stage was the main contributor for photochemical oxidation impact. Transportation also has a significant contribution to the environmental impacts.

Keywords: Biodiesel, palm oil, environmental impact, life cycle, Indonesia.

1. Introduction

Energy supply in the future is a problem that has been the attention of all nations, because human welfare in the modern life is highly correlated with the quantity and quality of energy used. For Indonesia, which is one of the developing countries, energy supply is a very important factor for promoting development. Along with the increasing developments especially in the industrial sector, economic growth and population growth, demand for energy continues to rise.

Energy consumption in Indonesia has been increasing rapidly in line with economic development and population growth. Energy has a significant role in achieving social, economic and environmental objectives to maintain sustainable development and to support national activities. Like many other countries, Indonesia too depends on fossil-based resources for energy; renewable energy resources have not yet been developed optimally.

Indonesia sees biofuels as one of the energy resources to accelerating economic growth, alleviating poverty, and creating employment opportunities. while also reducing greenhouse gas emissions under the Kyoto Protocol.Presidential decree has set in the target of Indonesia's energy mix in 2025, the use of renewable energy at 17%, of which 5% is biofuel energy [1].

To achieve the 2025 target, increasing use of biofuel is necessary, especially in the industrial and transportation sectors which are major consumers of fuels.

Biodiesel is an alternative to conventional diesel fuel and is defined as the mono-alkyl esters of vegetable oils and animal fats. Vegetable oils-based biodiesels can produced by transesterification process. From all of the biodiesel feedstocks, palm oil is the potential candidate.

One of the biofuels that has been developed in Indonesia is biodiesel. Biodiesel is an alternative to petroleum-based conventional diesel fuel and is defined as the mono-alkyl ester of vegetable oils and animal fats. Vegetable oils-based biodiesels can be produced from canola (rapeseed), cottonseed, palm, Jatropha curcas, peanut, soybean and sunflower oils by transesterification process. Among all these biodiesel feedstocks, palm oil is the most promising candidate because palm oil has highest oil yield among the many oil yielding plants [2]. Indonesia had 4,520.6 million ha of oil palm plantation in 2009 [3] and total crude palm oil produced is about 13,872,602 ton [4]. In the 2007, the export portfolio of the Indonesia's CPO was 11.6 million tons, the rest being consumed domestically [5]. In Indonesia, palm oil is mostly used as cooking oil. If it is to be used for biofuel, the demand for it will also increase, and can affect to converting other land use types to oil palm cultivation.

Energy conversion is always related with environmental impacts. The biodiesel production supply chain uses fertilizers and pesticides during oil palm cultivation, and conventional fuels for transportation as well as energy requirements for each process, all of which are associated with environmental burdens. This study is thus focused on evaluation on environmental impacts from the production of biodiesel from palm oil in Indonesia using life cycle assessment methodology.

2. Methodology

The Society of Environmental Toxicology and Chemistry (SETAC) defines LCA as "an objective process to evaluate the environmental burdens associated with a product, process or activity, by identifying and quantifying energy and materials used and wastes released to the environment and to evaluate and implement opportunities to effect environmental improvements". Life cycle assessment is the only tool that attempts to include the whole life cycle, and all environmental issues associated with a product or service [6].

2.1 Objectives

This study aims to investigate the environmental impacts of biodiesel production from palm oil by using Life Cycle Assessment methodology. This study will be useful for energy policy evaluation for the Government of Indonesia and owners of oil palm plantations, palm oil mills, and biodiesel companies, and other stakeholders.

2.2 Scope of the Study

This study focuses on environmental impacts of biodiesel production from palm oil as a material in Indonesia. The environmental parameters of interest are global warming, photochemical oxidation, acidification, eutrophication potentials, and abiotic resources depletion. Therefore emissions of CO, CO_2, CH_4, N_2O, NO_x, SO_2 are considered along with resources used. The environmental effects of vehicle production, vehicle maintenance and biodiesel use in vehicles are not included in the analysis. Figure 1 shows the system boundary of this study.

The data of oil palm plantation are collected from a plantation located in Banyuasin, South Sumatra province, Indonesia. All plantation data were assessed, including fertilizers and herbicides consumption, transportation of fresh fruit bunch to palm oil mill, and diesel consumption for land preparation. The data for palm oil mill production process are collected from a typical palm oil mill located in Banyuasin, South Sumatra province, Indonesia, located nearby the oil palm plantation. The data collected in this process include input and output materials, diesel and electricity consumption for the palm oil production process, and also transportation of palm oil from mill to biodiesel plant. Since the biodiesel pilot plant in South Sumatera province is not yet well developed, it was assumed that palm oil was transported using 20 m^3 truck-trailer and container ship to Jakarta province to produce biodiesel. The information on biodiesel production process is collected from a biodiesel pilot plant project in LEMIGAS (Research and Development Center of Oil and Gas Technology), located in South Jakarta, Indonesia. Some technical data for biodiesel process are also collected from literature. The functional unit for this study is 1 ton biodiesel (palm methyl ester).

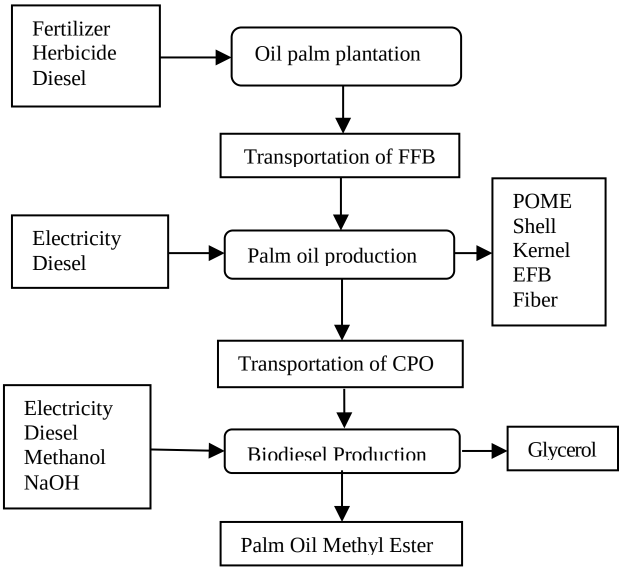

Figure 1. System Boundary of Biodiesel Production from Palm Oil.

3. Life Cycle Inventory

3.1 Oil Palm Plantation

Indonesia has become the major producer of palm oil in the world along with Malaysia. Oil palm trees generally begin to produce fruits 30 months after being planted in the fields with commercial harvest commencing six months later. However, the yield of an oil palm is relatively low at this stage. As the oil palm continues to mature, its yield increases and it reaches peak production in years seven to eighteen. Yield starts to gradually decrease after 18 years. The typical commercial lifespan of an oil palm is 25 years, after which it is no longer commercially viable for harvesting. In Indonesia, the species mostly planted is Tenera (also call DxP), which is a hybrid of species Dura and Pisifera. The oil content in Tenera fruit bunch is higher than Dura or Pisifera.

Data collection was done by interview with the plantation staff and from literature. The plantation has 143 trees/ha, density of crop is 9 × 9 m. Fertilizers used in this study are Dolomite, Urea, Rock Phospate, small amount of Borate (High Grade Fertilizer Borate), and ash from empty fruit bunches burned in the palm oil mill. The herbicides used are Paraquat and Glyphosate. Fertilizers are applied every year, the amount depending on the age of the tree. Herbicides are only used in young palm trees. One ton of fresh fruit bunches (FFB) can yield 0.2 ton crude palm oil. The fruit bunches are harvested manually using long-handled sickles. Since the harvesting system uses manual labor, so there is no fossil fuel input to the harvesting process. The unit process of oil palm plantation is shown in Figure 2.

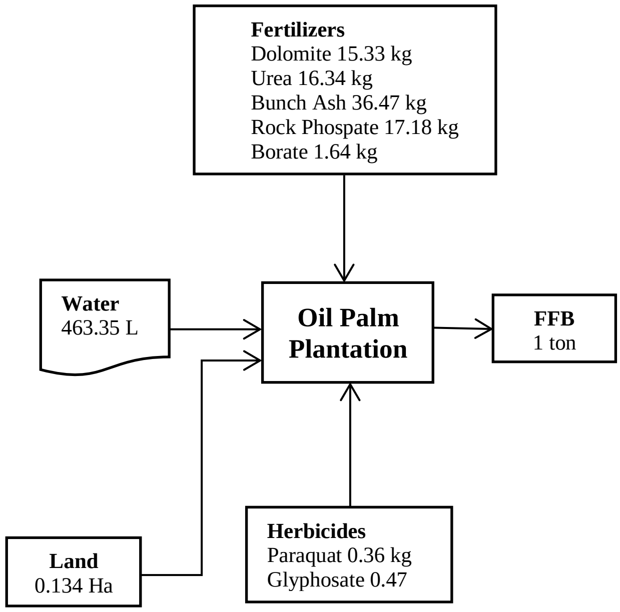

Figure 2. Unit Process of Oil Palm Plantation.

3.2 Palm Oil Production

After harvesting in plantation, the FFB are transported to the palm oil mill by truck. Location of the palm oil mill is near the plantation. The palm oil mill in this study has a capacity of 30 tons per hour or 600 tons per day which is a typical palm oil mill capacity in Indonesia (operating 20 hours per day). The FFB are transported to the loading ramp where they are unloaded to be processed in the first stage of the milling process. After unloading from the loading ramp, FFB are sent to the sterilizer where they are cooked for 90 minutes This process generates a high organic matter containing palm oil mill effluent which is sent to wastewater treatment ponds. The sterilized fruit bunches continue to the stripping process for separating the fruit from bunch. The unit process of palm oil production shown in Figure 3.

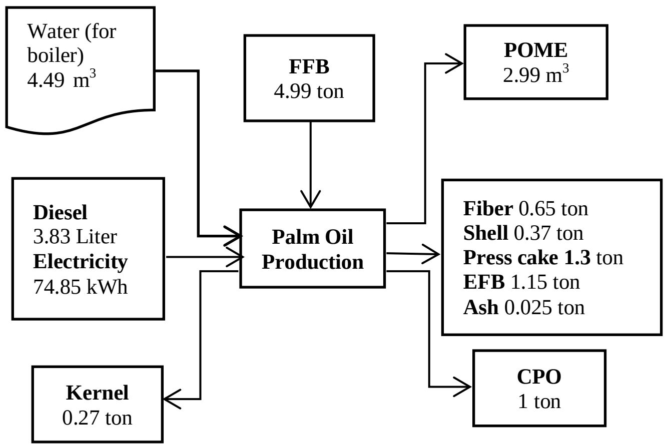

Figure 3. Unit Process of Palm Oil Production.

Fruits are digested to separate fruit from nut. Crude palm oil (CPO) extraction is done using screw press and continues to crude palm oil treatment station for cleaning the CPO from impurities. The empty fruit bunches that remain after extraction of CPO are incinerated to produce bunch ash for fertilizer in plantation.

Kernel treatment station processes the kernels and separates them into nuts, fiber and shells. Fiber and shells are used as fuel to produce steam. The palm oil mill sells the kernels to another company which uses them to produce crude palm kernel oil. The coproducts considered in this stage are CPO and kernel; the EFB, shell and fiber are considered to be internal recycled for energy.

Thus, the environmental burdens of the palm oil production process must be shared between CPO and kernel; allocation factor of CPO is 0.79 using mass allocation. For the production of CPO, two scenarios were applied in this calculation. The first scenario is the palm oil production without biogas recovery from the palm oil mill effluent (POME). This scenario is similar to the actual condition in palm oil mills. POME from FFB's sterilizer is sent to wastewater treatment ponds. For the second scenario, POME is sent to wastewater treatment ponds and digested by anaerobic bacteria and the methane is captured.

3.3 Biodiesel Production Process

The unit process for transesterification of palm oil to biodiesel is shown in Figure 4. The biodiesel pilot plant has a capacity 10 tons per day. The reactor for producing biodiesel from palm oil is a 1,500 L batch reactor. This plant uses two reactors (one operating and one standby). The temperature is 62°C. the crude palm oil is first pretreated for degumming before transesterification. The transesterification process uses sodium hydroxide and methanol. The transesterification process produces palm methyl ester (PME) with glycerol as by-product. Using mass allocation, the allocation factor for PME is 0.82. The PME layer is separated from the glycerol layer by using water to wash the mixture. The yield of biodiesel that can be produced is 78%.

Life cycle inventory of 1 ton biodiesel production is shown in Figure 5.

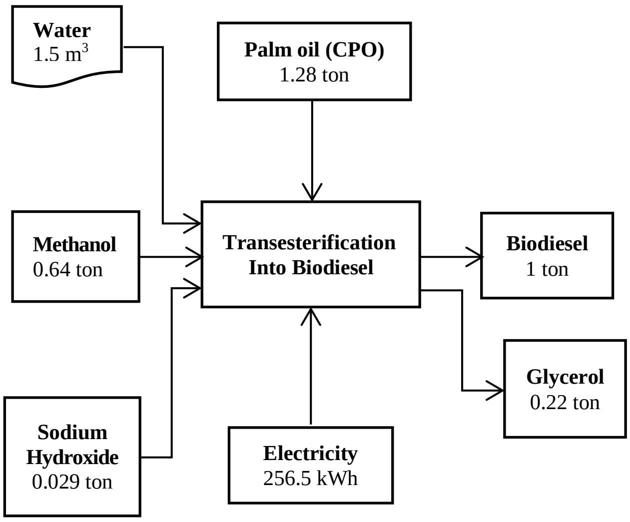

Figure 4. Unit Process of Biodiesel Production.

4. Results and Discussion

The categories considered in impact assessment for this study are global warming, photochemical oxidation, eutrophication, acidification, and abiotic resources depletion. These environmental impacts are caused by the emissions of CO_2, CO, NO_x, SO_2, CH_4, N_2O and use of non-renewable resources. The life cycle impact assessment methodology used is CML 2 baseline 2000 from SimaPro version 7.3. From all the processes included in biodiesel production life cycle (plantation, palm oil production, biodiesel production, and transportation), the major contribution comes from application of fertilizers and herbicides in the cultivation stage and electricity used in palm oil mill and biodiesel production since the electricity is purchased from the national grid. In Indonesia, electricity is mainly produced by coal fired steam turbines [7].

4.1 Global Warming Potential

Global warming potential from the various stages of the life cycle of biodiesel production process are shown in Figure 6 and Figure 7. Total GWP in scenario 1 from 1 ton biodiesel production is 690.7 kg CO_2-eq of which 58% comes from the cultivation stage, 16% from CPO production and 26% from biodiesel production.

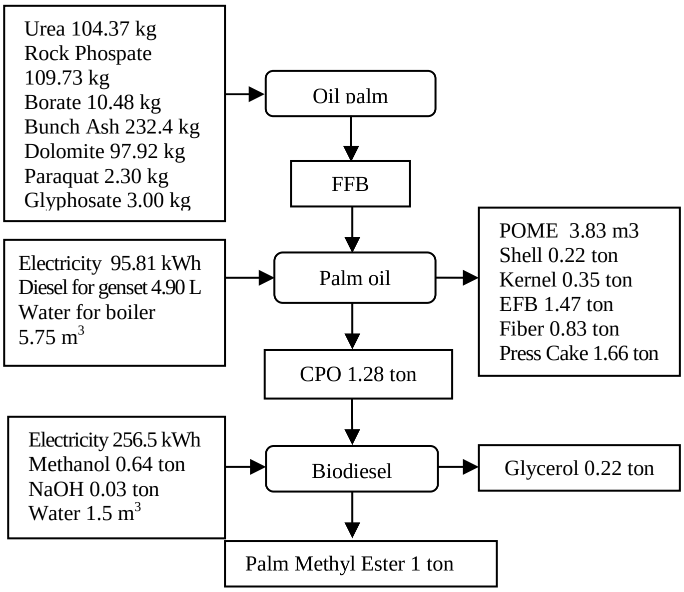

Figure 5. Life Cycle Inventory of 1 ton Biodiesel Production.

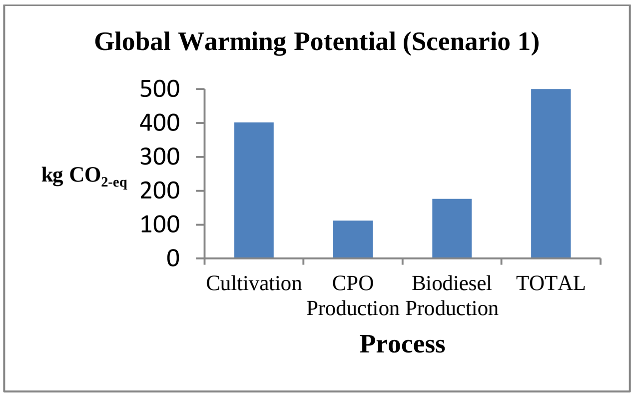

Figure 6. Global Warming Potential of Biodiesel Process (Scenario 1).

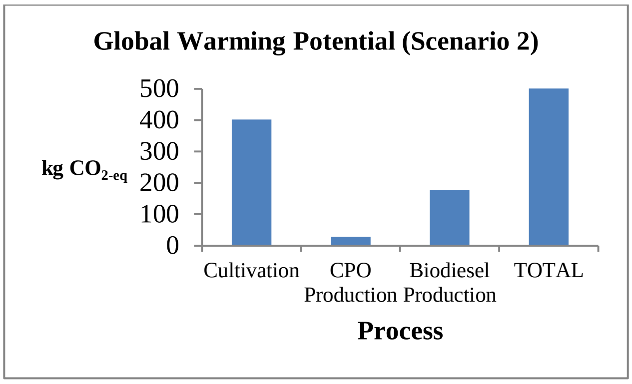

Figure 7. Global Warming Potential of Biodiesel Process (Scenario 2).

Cultivation stage contributes the highest amount for the GWP because of fertilizers and herbicide application. For the palm oil production process, the major contribution of GWP in scenario 1 is from electricity used in mill which is from the grid.

In scenario 2, the GWP decrease is significant amount compare with GWP in CPO production process in scenario 1, from 112 kg $CO_{2\text{-eq}}$ to 28 kg $CO_{2\text{-eq}}$. The biogas capture and utilization as electricity in scenario 2 makes a big dfference to the amount of GHG emissions.

Transportation also gives a significant contribution to the GWP since crude palm oil is assumed to be transported from Sumatra island to Java island using truck and container ship that use fossil-based diesel. Fossil-based diesel causes sizeable amount of CO_2 emission.

4.2 Photochemical Oxidation

The photochemical oxidation, often defined as summer smog, is the result of reactions that take place between nitrogen oxides (NO_x) and volatile organic compounds (VOC) exposed to UV radiation [8]. The Figure 8 for photochemical oxidation in scenario 1 shows that the biodiesel production stage was the major contributor to this environmental impact, with about 0.313 kg C_2H_4-eq, followed by CPO production process with about 0.146 kg C_2H_4-eq. This effect is due to the SO_2 and CO emissions from using electricity both in palm oil mill and biodiesel pilot plant. The electricity used in mill and pilot plant comes from electricity grid in Indonesia that uses coal as fuel. Overall photochemical oxidation for scenario 1 was 0.543 kg C_2H_4-eq.

Figure 9 shows that utilization of biogas contributes mainly to reduction of CH_4 emission. Photochemical oxidation on CPO production stage after biogas utilization is -0.003 kg C_2H_4-eq. Total photochemical oxidation in scenario 2 is 0.394 kg C_2H_4-eq of which 21% is from the cultivation stage, and 79% from biodiesel production stage.

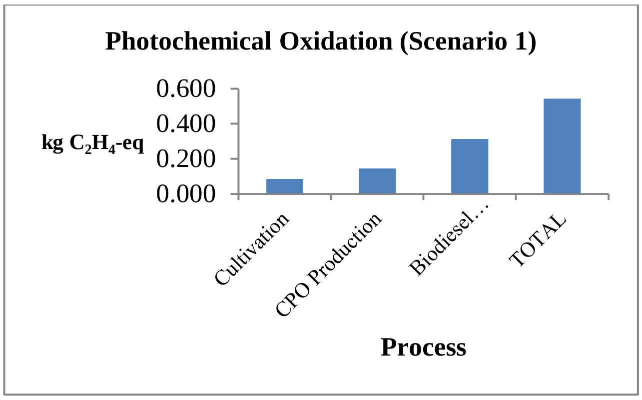

Figure 8. Photochemical Oxidation of Biodiesel Process (Scenario 1).

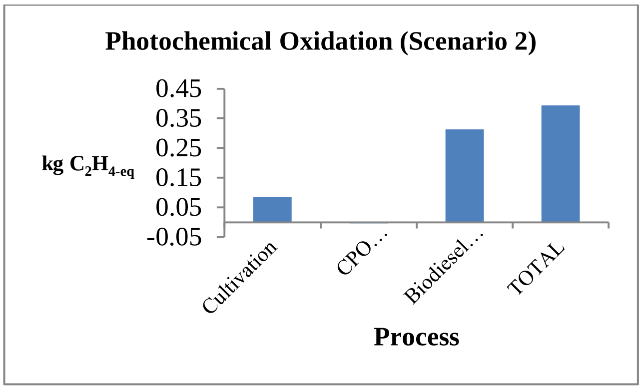

Figure 9. Photochemical Oxidation of Biodiesel Process.(Scenario 2)

4.3 Eutrophication

Figure 10 and Figure 11 shown the eutrophication impact assessment of 1 ton biodiesel process. In scenario 1, the total potential eutrophication impact is 1.145 kg $PO_{4\text{-eq}}$, 59% of this value comes from cultivation stage. The major contributor was from NO and NO_2 emitted from fertilizers and herbicides application during cultivation process.

Eutrophication from cultivation process is 0.673 kg PO_4-$_{eq}$. Total eutrophication in scenario 2 from 1 ton biodiesel production is 1.008 kg $PO_{4\text{-eq}}$ of which 67% comes from the cultivation stage, 12% from the CPO production stage and 21% from the biodiesel production stage.

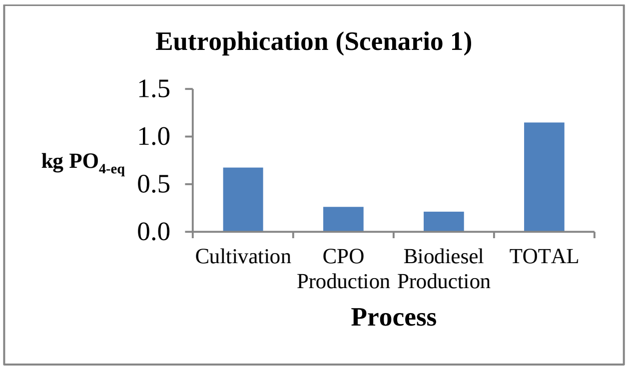

Figure 10. Eutrophication of Biodiesel Process (Scenario 1).

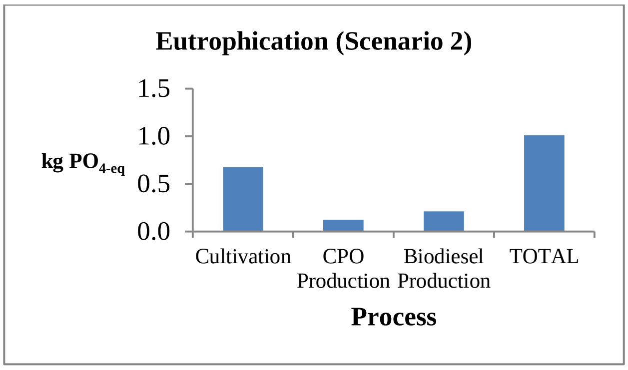

Figure 11. Eutrophication of Biodiesel Process (Scenario 2).

4.4 Acidification

When acids and compounds which can be converted to acids are emitted to the atmosphere and deposited in water and soil, the addition of hydrogen ions may eventually results in a decrease in pH, i.e. an increased acidity [9]. Figure 12 and Figure 13 show acidification of production 1 ton biodiesel.

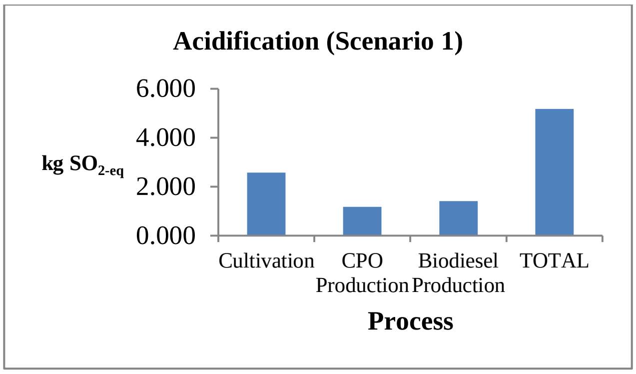

Figure 12. Acidification of Biodiesel Process (Scenario 1).

For scenario l, the total potential acidification impact is 5.175 kg SO_2-eq and the highest contributor is cultivation stage, with about 50% due to fertilizers and herbicides, followed by biodiesel production stage with about 1.417 kg SO_2-eq. scenario 1. For the second scenario, more than 50% of the total acidification comes from cultivation stage. CPO production shows significant reduction in acidification after biogas utilization with about 1.178 kg SO_2-eq in first scenario to 0.354 kg SO_2-eq in scenario 2.

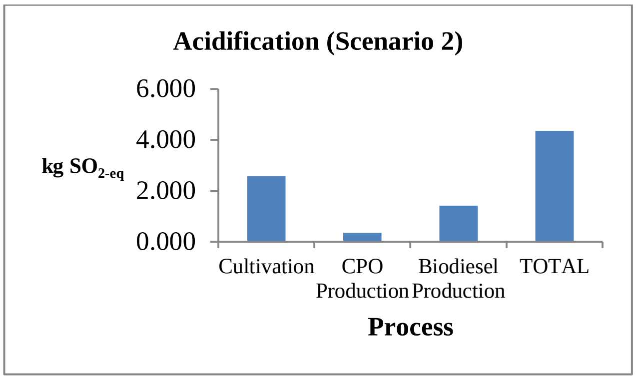

Figure 13. Acidification of Biodiesel Process (Scenario 2).

4.5 Abiotic Resources Depletion

Consumption of non-renewable resources, such as zinc ore and crude oil, thereby lowering their availability for future generations, is of interest [10]. Oil palm cultivation stage produced the highest amount of abiotic resource depletion impact of about 0.74 kg Sb-eq, or about 55% from the whole life cycle biodiesel process.

The use of urea fertilizer in plantation stage gave high contribution to abiotic depletion in the cultivation stage. Transportation process in CPO production stage also gave high amount on abiotic resource depletion impact, since diesel oil from fossil-based fuel were used for fuel in all transportation vehicles. For CPO production stage, abiotic resource depletion is about 0.575 kg Sb-eq and for biodiesel production stage with about 0.0344 kg Sb-eq. Figure 14 shows the abiotic depletion impact for scenario 1. In the second scenario, overall abiotic resource depletion is 1.32 kg Sb-eq, with cultivation stage, CPO production stage and biodiesel production stage contributing 57%, 40% and 3% respectively.

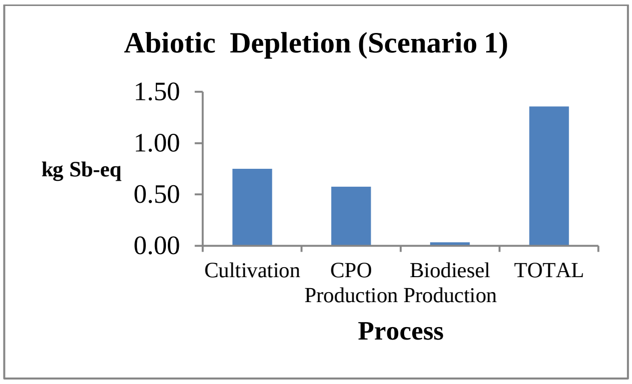

Figure 14. Abiotic Resources Depletion (Scenario 1).

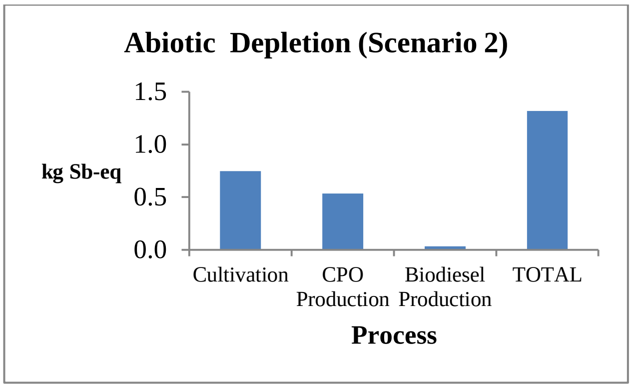

Figure 15. Abiotic Resources Depletion (Scenario 2).

5. Land Use Change

One of the factor that contribute the increasing of greenhouse gas emission in atmosphere is land use change that is also related to climate change. The international scientific community established that about 20% of global CO_2 emissions are generated through land use change and the conversion and degradation and forest. Indonesia is producing 3,014 Mt CO_2/yr from land use, land use change and forestry (LULUCF) [11]. From the calculation, emission from above ground is 5.44 ton C/ha.yr. This value is lower than what has been calculated in [12], 8 ton C or about 29 ton CO_2-eq/ha.yr. In this study, land required to produced 1 ton biodiesel from palm oil is 0.856 ha. Then, the greenhouse gas emission from land use change is 9.725 ton CO_2-eq/ton PME if peat lands are converted to oil palm plantations.

6. Conclusions

Biodiesel, produced largely from palm oil, is one of the renewable energy options that has been developed in Indonesia is. The study considered the environmental impacts and energy analysis from all the life cycle processes to produce biodiesel including oil plam plantation stage, transportation from plantation to mill, palm oil production stage, transportation from mill to biodiesel plant, and transesterification into palm methyl ester (biodiesel).

Based on the analysis conducted, it can be concluded that the major contributors of global warming potential are the use of fertilizers in plantation stage and electricity in palm oil mill and biodiesel plant.

The environmental impacts from the transportation stage can not be neglected since all of vehicles in this study use conventional diesel oil as fuel. Distance from mill to biodiesel pilot plant that transport by truck trailer and container ship also affect the amount of diesel use. Electricity is the second highest contributor of the environmental effect of biodiesel production since the grid mix in Indonesia is largely based on coal fired power plants leading to high emissions of CO_2, SO_2 and NO_x which are produced when coal burned to generate the electricity. Co-products from the milling process also can used for energy production such as fiber and shell to reduce the electricity using from the grid. Reducing of deforestation and biomass burning during land clearing can reduce the amount of greenhouse gas emission from land use change. The calculation of greenhouse gas emission from land use change in this study was based on literature studies, since there is no site specific data for peat land converted to crop land in this area.

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