Life cycle assessment of biodiesel production from crude palm oil: A case study of three Indonesian biodiesel plants

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Abstract. This study assessed the life cycle of biodiesel production from crude palm oil at three Indonesian biodiesel plants. The LCA stage is based on ISO 14040, which determines the goal, scope, inventory, impact assessment, and interpretation of the areas under study. However, the main of the research was to compare the carbon footprint biodiesel production processed. Furthermore, the study facilitated and utilized the Greenhouse Gas Protocol V1.02 as a method of life cycle impact assessment, with CO₂-eq evaluated using fossil fuel, land transformations, and biogenic. The results showed that palm cultivation using crude oil produced the highest pollution source in all categories with the highest at CO₂-eq. Also, palm cultivation using crude oil production at A, B, and C caused impact categories of 3.2 ton, 3.02 ton, and 2.85-ton fossil CO₂-eq. These were also extracted from the transportation and production process of crude palm oil in plants that use diesel fuel. Finally, in the production of biodiesel from biodiesel plants A, B, and C, in all categories, the highest impact source of pollution is caused by crude palm oil production.

1. Introduction

Biodiesel is an environmentally friendly renewable energy source, which emits lower carbon than fossil diesel. These carbon emissions from the use of diesel, such as CO₂, CO, and SO₂ cause air pollution and can trigger global warming and climate change [1]. Event though biodiesel has low emission in use, it produces CO₂ during its production process. A study of the Life Cycle Assessment (LCA) is therefore needed to calculate the carbon footprint in biodiesel production to determine the process causing the highest pollution. The results of the LCA is used to evaluate future biodiesel production, thereby, making the process environmentally friendly [2,3,4,5].

In Indonesia LCA calculation for biodiesel production is needed in accordance with ISO 14040:2006 [2]. The ISO is then ratified to become SNI ISO 14040:2016 [6]. Assuming the biodiesel plants in Indonesia do not have the results of LCA report, it means they do not follow ISO 14040 international policies. Previous researchers studied LCA analysis of Indonesia's biodiesel plants [8,5,3] with the crude palm oil used as feedstock. According to the analysis, the biodiesel production process in plants A, B, and C has the highest pollution due to the use of chemical fertilizers at the palm cultivation stage [5,7,8].
As previously described, the LCA stage is based on ISO 14040, and used to determine the goal, scope, inventory, impact assessment, and interpretation of the biodiesel plants. The previous studies which uses LCA with crude palm oil shows several research such as IPCC 2007 [5,7] and the CML 2 baseline 2000 [8]. IPCC 2007 is in the impact category and potential to global warming (GWP) [5,7]. Also CML 2 baseline 2000 consists of the results obtained from calculating the eutrophication (E), acidification (A), global warming potential (GWP), human toxicity (HT), photochemical oxidation (PO), marine aquatic eco-toxicity (MAE), terrestrial eco-toxicity (TE), fresh water aquatic eco-toxicity (FWAE), ozone layer depletion (ODP), and abiotic depletion (AD) impact on the plants[8,9,10].

The current study utilizes the Greenhouse Gas Protocol V1.02 as an LCA method of for biodiesel productions. It calculates impacts in various categories previously compared. However, in this research was calculated impact categories: fossil CO$_2$eq, biogenic CO$_2$eq, CO$_2$eq from land transformation, and CO$_2$ uptake. [11]. The objective of this research, therefore, was to compare the results of carbon footprint in biodiesel production from three Indonesian biodiesel plants. In addition, recommendations were provided to ensure that the stages involved in the biodiesel production processes of plants A, B, and C are environmentally friendly.

2. Materials and Methods

2.1 Scope

Figures 1, 2, and 3 sequentially show the system boundary of the biodiesel production from plants A, B, and C. The function unit used in this study is 1 ton of biodiesel.

Figure 1: System boundary of biodiesel production from biodiesel plant A [8].

![Figure 1](image1)

Figure 2: System boundary of biodiesel production from biodiesel plant B [5].

![Figure 2](image2)
2.2 Inventory
This study uses the SimaPro 8.4.0.0 faculty version software and Ecoinvent 3 database. Secondary data was obtained from biodiesel production of plants A, B, and C, as shown in tables 1, 2, and 3.

Table 1. Inventory data of biodiesel production from biodiesel plant A [8]

| Compounds       | Units | Inputs  | Outputs |
|-----------------|-------|---------|---------|
| Sodium Hydroxide| Ton   | 0.029   |         |
| Crude palm oil  | Ton   | 1.28    |         |
| Methanol        | Ton   | 0.64    |         |
| Electricity     | kWh   | 256.5   |         |
| Water           | Ton   | 1.5     |         |
| Glycerol        | Ton   | 0.22    |         |
| Biodiesel       | Ton   | 1       |         |

Table 2. Inventory data of biodiesel production from biodiesel plant B [5]

| Compounds       | Units | Inputs  | Outputs |
|-----------------|-------|---------|---------|
| Sodium Hydroxide| Ton   | 0.08    |         |
| Crude palm oil  | Ton   | 1.21    |         |
| Methanol        | Ton   | 0.27    |         |
| Electricity     | kWh   | 15.65   |         |
| Water           | Ton   | 1.701   |         |
| Glycerol        | Ton   | 0.27    |         |
| Biodiesel       | Ton   | 1       |         |

Table 3. Inventory data of biodiesel production from biodiesel plant C [3]

| Compounds       | Units | Inputs  | Outputs |
|-----------------|-------|---------|---------|
| Sodium Hydroxide| Ton   | 0.006   |         |
| Crude palm oil  | Ton   | 1.14    |         |
| Methanol        | Ton   | 0.15    |         |
| Electricity     | kWh   | 256.5   |         |
| Water           | Ton   | 0.2     |         |
| Glycerol        | Ton   | 0.1     |         |
| Biodiesel       | Ton   | 1       |         |

2.3 Impact assessment
The characterization factors per substance are identical to the IPCC 2007 GWP (100a) method in SimaPro. However, the difference is that carbon uptake and biogenic carbon emissions are included in this method with a distinction between 1) Carbon uptake (CO₂ that is stored in trees and plants as they grow). 2) Carbon from land transformation (direct impacts). 3) Biogenic carbon (carbon originating
from biogenic sources such as trees and plants. 4) Fossil-based carbon (carbon originating from fossil fuels) [11].

2.4 Interpretation  
Each biodiesel produced has different amounts of carbon footprint, which is dependent on mass and energy input.

3. Results and Discussions  
3.1 Weighting of Carbon Footprint  
Weighting represents the magnitude of impact on carbon footprint on each biodiesel production process from biodiesel plant A, B, and C, with each expressed in a ton. Figures 4, 5, and 6 analyze the weighting of the carbon footprint during palm cultivation till crude palm oil is produced with high pollution source found in fossil CO₂eq. Furthermore, the palm was cultivated until crude palm oil produced at A, B, and C were 3.2, 3.02, and 2.85 tons. Fossil CO₂eq was extracted from the transportation and production process of crude palm oil in plants that use diesel fuel resulting to pollution at the cultivation stage due to the use of chemical fertilizers [5,7,8]. With the production of 2.37, 2.24, and 2.11 tons, the largest amount of biogenic CO₂eq was extracted from forest and land burning when clearing the palm plantations and from the use of biomass fuel in boiler engines [12,13,14,15,16,17,18]. Palm was cultivated till crude oil was produced in A, B, and C which lead to the production of CO₂ uptake by -5.97 ton, -5.65 ton, and -5.32 ton.

Figure 4. Weighting of the carbon footprint of palm cultivation until crude palm oil production A.

Figure 5. Weighting of the carbon footprint of palm cultivation until crude palm oil production B.
Figures 7, 8, and 9 indicate the weight of the carbon footprint production in A, B, and C, with the highest pollution in fossil CO$_2$eq. In plant A, the use of methanol and electricity caused pollution in sequences of 0.386 and 0.1821 tons. Similarly, the use of methanol and sodium hydroxide caused pollution of the highest fossil CO$_2$eq, in a sequence of 0.163 ton and 0.107 ton in plant B, while methanol and electricity led to sequences of 0.09 and 0.182 tons in plant C. The biodiesel production process from plants A, B, and C is more environmentally friendly in oil palm plantations without burning the forest. It is advised that a system of selective logging of trees with large and clear plantation land be conducted as this solution tends to reduce CO$_2$ pollution. Furthermore, transportation that utilizes diesel fuel and reduces its usage in the crude palm oil production process should be avoided.

**Figure 6.** Weighting of the carbon footprint of palm cultivation until crude palm oil production C.

![Figure 6](image)

**Figure 7.** Weighting of the carbon footprint of biodiesel production in biodiesel plant A.

![Figure 7](image)
Figure 8. Weighting of the carbon footprint of biodiesel production in biodiesel plant B.

Figure 9. Weighting of the carbon footprint of biodiesel production in biodiesel plant C.

4. Conclusion
The most environmentally friendly impact assessment of carbon footprint from other biodiesel plants is planted C. However, the highest impact in all categories is caused by the palm cultivation through crude palm oil production. It is, therefore, recommended that palm should be cultivated till crude palm oil production in A, B, and C becomes environmentally friendly without using diesel fuel transportation technique, thereby, reducing the consumption of diesel during the production process.

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References
[1] Budiman A, Kusumaningtyas R D, Pradana Y S and Lestari N A 2017 Biodiesel : Bahan Baku, Proses dan Teknologi, Yogyakarta: Gadjah Mada University Press
[2] ISO 14040 2006 Environmental management — Life cycle assessment — Principles and framework, Switzerland : ISO
[3] Pleanjai S, Gheewala S H and Garivait S 2004 The Joint International Conference on Sustainable
Energy and Environment (SEE), Hua Hin, Thailand

[4] Hasibuan S and Thaheer H 2017 *Seminar Nasional* Inovasi Dan Aplikasi Teknologi Di Industri, Malang

[5] Siregar K, Tambunan A H, Irwanto, A K, Wirawan S S and Araki T 2015 *Energy Procedia* 65 170 – 179

[6] SNI ISO 14004 2016 *Manajemen lingkungan — Penilaian daur hidup — Prinsip dan kerangka kerja*, Badan Standardisasi Nasional

[7] Siregar K 2015 *Advanced Science Engineering Information Technology*, 5: 293-299

[8] Soraya D F, Gheewala S H, Bonnet S and Tongurai C 2014 *Journal of Sustainable Energy and Environment* 5 27-32

[9] Peiro´ L, Talensn L L, Me´ ndez V G, Durany X and Gabarrell I 2010 *Energy* 35 889–893

[10] Gasol C M, Salvia J, Serra J, Anto A, Sevigne E, Rieradevall J and Gabarrell X 2012 *Biomass and Bioenergy* 40 71-81

[11] Soldal E and Modahl I S 2016 *Greenhouse gas protocol Scope 3 reporting*, Borregaard , Europe.

[12] Reijnders L and Huijbregts MAJ 2008 *Journal of Cleaner Production* 16 477-482

[13] Henson I E 2005 *Journal of Tropical Forest Science* 17(2) 279-29

[14] Oliva F G, J Robert L S and Kelly E 1999 *Geoderma* 88 1-12

[15] Perez J A G, Vila F J G, Almendros G and Knicker H 2004 *Environment International* 30 855– 870

[16] Yusoff S and Hansen S B 2007 *Int J LCA* 12(1) 50-58

[17] Inubushi K, Furukawa Y, Hadi A, Purnomo E, Tsuruta H 2003 *Chemosphere* 52 603–608

[18] Noordwijk MV, Cerri C, Woomer P Nugroho K and Bernoux M 1997 *Geoderma* 79 187-225

[19] Reijnders L and Huijbregts M A J 2008 *Journal of Cleaner Production* 16 1943-1948

[20] Vleeshouwers L M and Verhagen A 2002 *Global Change Biology* 8 519-530

[21] Goedkoop M, Oele M, Vieira M, Leijting J, Ponsioen T and Meijer E 2016 *SimaPro Tutorial, Creative Commons*, San Francisco, California