CRADLE TO GATE SIMPLE LIFE CYCLE ASSESSMENT OF BIODIESEL PRODUCTION IN INDONESIA

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Abstract

The focus of this research is to analyze potential environmental impact in the supply chain of palm oil biodiesel industries. Simple Life Cycle Assessment (LCA) is applied to analyze impacts, produced by the three main units in the supply chain of Palm-Oil-based Biodiesel, which are Palm Plantation, CPO mill, and Biodiesel Plant. We developed LCA calculation model using spreadsheet software, used to assess a number of input scenarios to evaluate the best scenario, in variation of: land quality, land area and the rate of clearing, land clearing technique and type of the original land. The biggest potential environmental impact is the contribution to global warming impact which emissions are produced mostly from unit plantation. Although plantation has biggest potential to contribute to environmental impact, it also gives biggest reduction to global warming impact. In general, the biggest environmental impact in the LCA category is climate change, followed by photo-oxidant formation and eutrophication. The biggest impacts in the supply chain are from the plantation, especially when choosing the right technique for land clearing. In addition, due to LCA linearity nature, the scenario that we tested does not change the total accumulative environmental impacts.

Keywords: environmental impact analysis, life cycle assessment, palm oil biodiesel

1. Introduction

Indonesia is one of the countries which are highly dependent on fossil fuel, especially in the transportation and industry. After the Asian economic crisis, Indonesia’s growth has been steady, which also means that our energy needs is increasing. By 2007, daily national oil consumption reaches 1.2 million barrel and is predicted to increase by 2.8% annually, showing a trend that will not easily be coped with due to difficulties in finding substitution oil. [1] The contrast between energy consumption and available energy reserves, marked the entry of Indonesia's into energy crisis and also the financial burden of importing oils. Therefore energy resource diversification is indispensable to reduce oil dependency.

Responding to the issue, Indonesian Government directed their focus on renewable energy, with the main highlights on biofuel and set its very first biofuel national policy as part of the efforts to ensure the fuel supply availability [2]. The government also saw an opportunity to create new jobs (especially in rural areas), to strengthen the agricultural sector, as well as to discover new export opportunities [3]. Early government plan estimates that biofuel will cover 10 percent of total fuel consumption for transportation sector, creating thousands of employment opportunities and self-sufficient energy for rural areas.

Biofuel can be derived from these commodity crops, such as soybean [4], rapeseed oil [5], palm oil, sunflower [6], jathropa [7-8], even from coffee [9]. However, CPO-based biodiesel is the strongest candidates to be developed, because this commodity has a relatively low production cost and has equal performance compared with diesel fuel properties, therefore engine modification is relatively minimum [7,10]. In addition, Palm oil as raw material of the biodiesel has been produced in massive quantity at industrial scale. Indonesia is the largest palm oil producer in the world and also the second largest palm oil exporter in the world (after Malaysia) [11]. Currently, Indonesia produces 17.37 million tons of CPO to the area of land 6.78 ha [12].

Fulfilling this medium and long-term target will require the establishment of the new land, and also CPO as raw material for biodiesel, new factories and other infrastructures. It is estimated that total of 5.25 ha new plantation land must be cultivated by 2015 to supply biodiesel production. [13]

This land expansion issue has created one of the main challenges in developing palm oil for biodiesel: environmental issues, and has been a subject of critique, especially from international NGOs. In the recent years their voice has influence the export market of CPO. There is recent news that the major importer of CPO, Unilever had pending the future import from a major CPO producer pending an investigation on environment violation issues [14]. Therefore, we need to calculate accurately the impact of the biodiesel supply chain to the environment, then come up with strategy to eliminate or reduce the impact.

One method that has been gaining popularity to measure the environmental impacts is LCA or Life Cycle Assessment. ISO 14040:2006 standards define LCA as the collection and evaluation of input and output and the potential environment impact of a system life-cycle product [15]. LCA is a tool to analyze the effects on the environment of each stage in a product life cycle, from resource extraction, material production, component production, to final product production, and management functionality after the product is consumed, either with re-used, recycled or discarded (valid from cradle to grave). The entire system of units processed is included in the product life cycle is called a product system.

LCA's main approach is set the object of analysis as a whole big picture, which is the main strength, due to its simplicity, however at the same time, its limitations. These limitations are: LCA cannot measure the impact of a local area; LCA does not provide a framework for risk assessment studies to identify the local impact that caused by a certain function of a facility in a specific place; LCA is a steady state approach, and not a dynamic approach, which means for a time limit, all the conditions including the technology is considered permanent [16].

LCA model focuses on the physical characteristics of industrial activities and other economic processes, and does not include market mechanisms, or effects in the development of technology. In general, LCA considers all processes are linear, both in economic and in the environment. LCA is a tool based on linear modeling [16].

2. Methods

LCA methodology consists of four phases namely goal and scope definition, inventory analysis, impact assessment and interpretation.

Table 1. National Biodiesel and Biofuel Roadmap 2006-2025

Years	2005-2010	2011-2015	2016-2025
Biodiesel	10% Diesel Fuel Market mandatory (2.41 million kiloliter-kl)	15% Diesel Fuel Market Mandatory (4.52 million kl)	20% Diesel Fuel Market Mandatory (10.22 million kl)
Total Biofuel	2% National Energy Mix (5.29 million kl)	3% National Energy Mix (9.84 million kl)	5% National Energy Mix (22.26 million kl)

(Source: Government of Indonesia, Jakarta [13])

Goal and scope definition is the first phase when we determine a work plan for the entire project. It consists of the goal definition, scope definition, function definition, functional unit, alternatives and reference flows. We define our goals to have units of measurement that could be used as an environment indicator on each chain of the biodiesel supply chain. The scope is cradle-to-gate, which start by land clearing to biodiesel product comes out from the factory. With this level of detail in mind, we decided to utilize secondary data source, collected from journals, research result, and related books.

The next phase, inventory analysis phase is where the production systems is defined, which each incoming and outgoing flow of the system is translated to environmental interventions, translated into inputs outputs table. Extraction and consumption of natural resources and emissions, and also process of the exchange environment in each phase that are relevant in the product life cycle is compiled in a Life Cycle Inventory (LCI). LCI will use secondary data, starting from plantation (including land clearing) [17-25], CPO production through CPO factory [17-18,21], and biodiesel factory [18].

In palm plantation, there are two major land clearing techniques in Indonesia, slash and burn or slash and mulch (without burn). We must also consider whether the original land is forest-lands or peat-lands. Due to cost associated with land clearing, many plantations did not open all allocated land that they have, so they open it in 2 or 3 stages.

During the plantation, we consider land productivity, total land area, fertilizer use (and its elements), pesticides, water and fuel use [26]. We calculated that when palm oil grows and produces biomass, the plantation not only brings out the emission (CO_2) but also absorbs them, which we could see as net CO_2.

In CPO and biodiesel production, we use extraction rate of 0.23 from Palm Fresh Fruit Bunch (FFB) to Crude Palm Oil (CPO) and 0.87 for CPO to Biodiesel. These numbers are commonly used for first generation production technology.

For each stage of production, we use a detailed spreadsheet to list and calculated all the input needed and output produce in the form of input output tables.

The graphical representation for the LCA calculation used in this paper is shown in Figure 1.

In the phase of impact assessment, result from analysis of inventory is processed and interpreted in the context

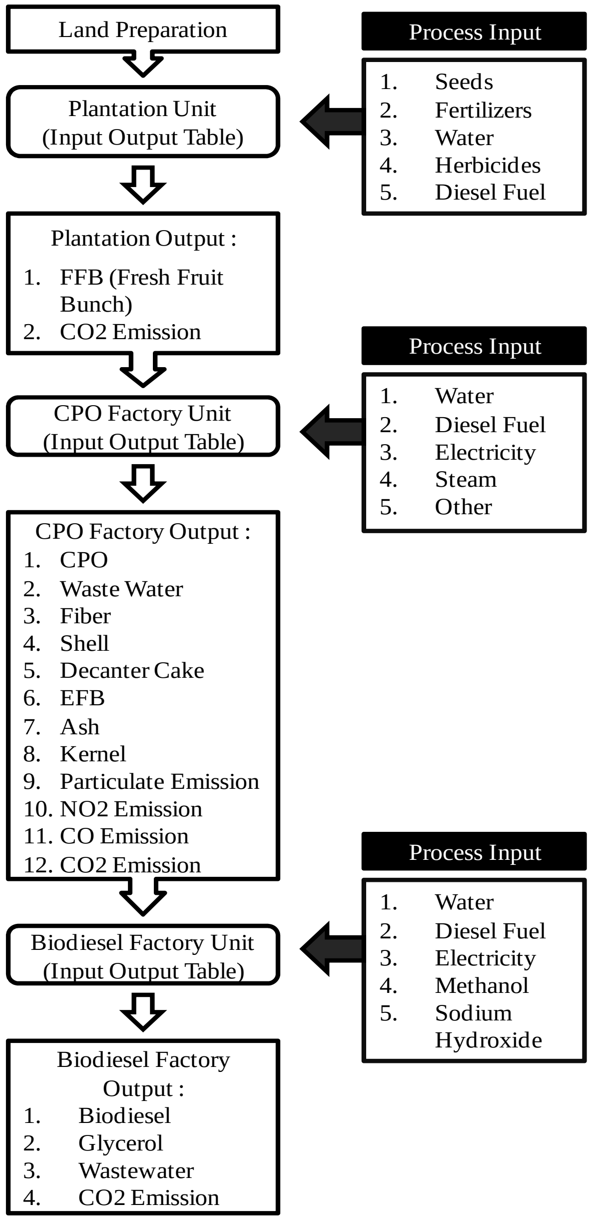

Figure 1. Simplified Representation of Simple LCA Calculation

Table 2. LCA Environmental Impacts based on ISO 14040

Environmental Impact	Description
Depletion of abiotic resources	Abiotic resources are natural resources (including energy resources) such as iron ore, crude oil, & wind energy, which are not alive.
Impact of land use (land competition)	This category is related to the reduction of land as natural resources
Climate change	Climate change is defined as the impact of emissions on the human contribution to global warming and increase the surface temperature of the earth. This effect is known as greenhouse gases (GHG)
Stratospheric ozone depletion	Stratospheric ozone layer depletion is related to the ozone layer depletion as a result of emissions caused by human/ anthropogenic. This causes the size of the faction of the solar radiation of UV-B rays that reach the surface of the earth
Human toxicity	Toxic substances that could threaten human health
Ecotoxicity (3 Groups)	Freshwater aquatic ecotoxicity Marine aquatic ecotoxicity Terrestrial ecotoxicity
Photo-oxidant formation	The formation of photo-oxidant is a formation of reactive chemical compound (such as ozone) due to sunlight, with the main sources of primary air pollution. This reactive compound can injure humans and ecosystems and can harm crops. Photo-oxidant can be formed on troposphere by the influence of ultraviolet rays through the process of photochemical oxidation of Volatile Organic Compounds (VOCs) and carbon monoxide (CO) with the nitrogen oxide (NOx).
Acidification	Acid pollution causes acid rain and makes impacts to soil, underground water, surface water, biological organisms, ecosystems, & materials.
Eutrophication	Eutrophication covers all potential impact caused by excessive macro nutrient, such as nitrogen (N) and phosphorus (P). Excessive amount of nutrients can cause the exchange of species composition & unwanted increase in the production of Biomass in freshwater & terrestrial ecosystems.

of the environment impact and translated to a contribution for the relevant impact categories such as depletion of abiotic resources, climate change, acidification, and so on. In baseline impact categories in LCA, it consists of 11 measured impacts.

In accordance with the LCA methodology, the impact assessment phase is consisted of impact category selection, the selection methods of characterization (the indicator category, model characterization, and characterization of factors), classification, characterization, normalization, grouping, and weighting.

We use the baseline impact category, due to the difference of industry characteristics of each production chain. Characterization method used was the basic method that is used on all categories on the baseline impact categories [16], except for the acidification, since we have difference baseline category. We then conduct the classification to identify and measure the input and output that contributed to the impact.

From the classification stage, there are only 9 accessed impacts, which are depletion of abiotic resources, climate change, human toxicity, ecotoxicity (freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, and terrestrial ecotoxicity), photo-oxidant formation, acidification, and eutrophication. The rest impacts that are not accessed are: impact of land use and stratospheric ozone layer depletion, due to unavailability of data input and output that can be identified.

Table 3. Example of Input Output Table of Plantation Unit

Input		Output		
Seed		FFB	1	ton
Fertilizer		Emission		
N (Ammonium suplhate) (kg)	50	CO_2	2.72	ton
P (ground rock fosfat) (kg)	14			
K (Potassium chloride) (kg)	35			
Mg (kieserite 26% MgO) (kg)	9			
B (Sodium borate decahydrate) (kg)	1			
Water (m^3)	1400			
Herbicides				
Paraquat (kg)	0.2			
Glyphosate (kg)	0.4			
Diesel (Lt)	0.33			
CO_2 (ton)	6.6			

Result of processing the data for the measurement of impact is shown in the time period from 1 year to 25 years and are grouped based on 3 major chains in the supply chain, namely plantations, CPO Mill (MCC), and the biodiesel plant.

Table 4. Classification on Plantation Unit

Input/output	Potential Impacts
Input	
Seed	-
N Fertilizer (ammonium sulphate)	Depletion of Abiotic Resources
N Fertilizer (ammonium sulphate)	Eutrophication
Fertilizer P (from ground rock fosfat)	Depletion of Abiotic Resources
Fertilizer P (from ground rock fosfat)	Eutrophication
Fertilizer K (from potasium klorida)	Depletion of Abiotic Resources
Fertilizer Mg (from kieserite 26% MgO)	Depletion of Abiotic Resources
Fertilizer B (Sodium borate decahydrate)	Depletion of Abiotic Resources
Water	-
Paraquat	Depletion of Abiotic Resources
	Depletion of Abiotic Resources
	Human Toxicity
	Freshwater Aquatic Ecotoxicity
Glyphosate	Marine Aquatic Ecotoxicity
	Terrestrial Ecotoxicity
	Eutrophication
Diesel	Depletion of Abiotic Resources
CO_2 Absorption	-
Output	
FFB	-
CO_2 Emission	Climate Change
CO Emission	Photo-Oxidant Formation
CH_4 Emission	Climate Change Photo-Oxidant Formation
NMV OC Emission	-
N_2O Emission	Climate Change

3. Results and Discussion

A spreadsheet model was developed to detail calculate each input and output. Here is shown the result of data processing using the baseline input scenario. Input for the baseline scenario is total area of 10,000 hectares (with 3,000 ha of land, 3,000 ha and 4,000 ha for three consecutive years) with land productivity class 1, the land type peat-land, and the slash and burn technique. This involves the calculation the whole biodiesel production chain, consist of: one unit plantation, one CPO mill and one biodiesel factory. The result after normalization is shown in Table 5. Normalization permits easier comparison between impacts.

Table 5 shows that in the biodiesel industry the highest environmental impact is climate change, followed by photo-oxidant formation and eutrophication. We also identify the causes of the impact that significantly contributes to the accessed impacts (Table 6). If we measure the CO_2 absorption by the plantation then we get normalization value of 1.05E-03. Subtracting this value to the original impacts value from Table 5, will give us a net impact of 7.96E-04.

Table 6 shows that from the 3 major impacts, each has their own major cause which could give a strategy on how to avoid or reduce them. Table 7 shows the calculation of impacts along the supply chain and shows that the plantation unit environmental impacts dominate the impacts accessed.

We then use the spreadsheet model to measure the effects of different land productivity class, area and land clearing rate, different land origin (forest or peat-land). In this measurement, all other variables are unchanged and using the baseline condition.

Effects of Different Land Productivity Class. Land productivity class from 1 to 4 is a measure of land productivity. The smaller class number will yield higher productivity.

Since the table provides the input and output that is formulated to 1 ton FFB product. With larger amount of FFB production, input and output will be larger and will cause a greater impact as well. Therefore, the higher the land productivity results in higher environmental impact due to higher production volume.

Effects of Different Total Area and Land Clearing Rate. In this calculation, we use 4 different land area and clearing stages. Scenario 1 has total area of 10,000 ha with land clearing of consecutive years per 3,000 ha, 3,000 ha, 4,000 ha. Scenario 2 has total area 10,000 ha with 2,000 ha per year for 5 years. Scenario 3 has a total area of 6,000 ha with 3,000 ha per year consecutively. Scenario 4 has a total area of 6,000 ha with consecutive rate 3,000 ha, 2,000 ha and 1,000 ha.

From the result shown on Table 10, it can be seen that in the scenario with the same total area, the difference between total environment impacts is very small. The impact calculation on scenarios that use total land area of 6,000 ha (or 60% of the 10,000 ha) has an average value of 60.38% (close to 60%) from the calculation of impact on the environment covering 10,000 ha of land. This shows the linearity principles of LCA.

Table 5. Impact Assessment by Using Baseline Input Scenario (Total 25 Years)

Impact	Total	% Grand Total
Depletion of Abiotic Resources	1.26E-06	0.068
Climate Change	7.47E-04	40.52
Human Toxicity	6.53E-08	0.004
Freshwater Aquatic Ecotoxicity	9.81E-07	0.053
Marine Aquatic Ecotoxicity	1.18E-11	0.000
Terrestrial Ecotoxicity	7.75E-07	0.042
Photo-Oxidant Formation	6.19E-04	33.55
Acidification	6.28E-06	0.341
Eutrophication	4.69E-04	25.42
Total	1.84E-03	100

Table 6. Identification of Significant Impact

Impact	Significant Impact	Cause
Climate Change (40.52%)	98.64% reduction is caused by plantation unit	Peat-land clearing with slash and burn techniques
Photo-oxidant formation (33.55%)	56.67% impact is caused by biodiesel plant	The use of methanol in biodiesel production
	42.74% impact is caused by plantation unit	Peat-land clearing with slash and burn techniques
Eutrophication (25.42%)	99.42% impact is caused by plantation unit	The use of ammonium sulphate and ground rock phosphate fertilizer

Table 7. Contribution Percentage per Unit to Environmental Impacts

Unit	Total Impact	CO_2 Absorption	% Total Impact
Plantation	1.47E-03	1.05E-03	79.70
Mill CPO	1.89E-05	-	1.03
Biodiesel Plant	3.55E-04	-	19.27
Total	1.84E-03	1.05E-03	100

CO_2 Effects of Different Total Area and Rate of Land Clearing with Absorption. Since the study focuses only on the impacts, therefore for all previous calculation, we do not measure the absorption of GHG by the palm plantation. However, in the different land clearing rate we have overlapping conditions where the rest of the forest-land still available to absorb CO_2 and at the same time the plantation is maturing to also absorb CO_2.

Effects of Different Land Origin. Next scenario is calculating the LCA for different original land type, mainly between peat-land and forest-land, using the baseline conditions for other input variables.

Table 8. Total Impact for Different Land Productivity Class (25 Years)

Land Productivity Class	Average Productivity (ton/year)	Total Impact
1	24.40	1.8436E-03
2	22.65	1.7498E-03
3	20.26	1.6217E-03
4	17.97	1.5020E-03

Table 9. Total CO_2 Absorption for Different Land Productivity Class

Land Productivity Class	Average Productivity (ton/year)	Total CO_2 Absorption
1	24.40	1.0472E-03
2	22.65	1.0460E-03
3	20.26	1.0437E-03
4	17.97	1.0439E-03

Table 10. Total Impact by Using Scenarios of Total Area and Rate of Land Clearing

	Scenario			
	1	2	3	4
Total Impact	1.8436E-03	1.8315E-03	1.1099E-03	1.1089E-03
	% (1 as base)		60.20%	60.15%
	% (2 as base)		60.60%	60.55%

Table 11. Impact Values during Non Productive Stage

/ha	Emission	Absorption	Contribution
Maturing Palm Plantation (non-productive stage)			
CO_2	3.98E+04	9.66E+04	Climate Change
Forest land			
CO_2	1.21E+05	1.64E+05	Climate Change

(source: [18, 27])

Table 12. Total Impact by Using Scenario of Land Type

Land Type	Total Impact
Peat-land	1.84E-03
Forest-land	1.12E-03

Table 13. Total Impact for Scenario of Land Clearing Techniques

Land Clearing Techniques	Total Impact
Slash and Burn	1.84E-03
Non-Burn	1.32E-03

Table 14. Environmental Impact per Unit along the Supply Chain as a Sustainability Indicator for the Biodiesel Industry

Impact	Land Clearing	Plantation (per ton FFB)		CPO Mill (per ton CPO)	Biodiesel Plant (per ton biodiesel)
	Emission	Emission	Absorption	Emission	Emission
Depletion of Abiotic Resources	-	1.14E-02	-	1.10E-01	3.32E-10
Climate Change					
CO2	9.50E+05	3.96E+00	6.60E+00	1.67E+02	1.69E+02
CH4	2.99E+04	8.31E+01	-	-	-
N2O	-	1.64E+02	-	-	-
Human Toxicity	-	6.00E-03	-	2.59E+00	-
Fresh Water Aquatic Ecotoxicity	-	3.68E-01	-	-	-
Marine Aquatic Ecotoxicity	-	1.12E-03	-	-	-
Terrestrial Ecotoxicity	-	3.84E-02	-	-	-
Photo-oxidant Formation			-	1.32E-01	1.47E+01
CO	1.18E+03	-	-	-	-
CH4	8.55E+00	8.31E+01	-	-	-
Acidification	-	-	-	1.51E+00	-
Eutrophication	-	1.11E+01	-	2.80E-01	-

The results above shows that calculated total impact for the peat-land will have greater environmental impact than using forestland for the plantation.

Effects of Different Land Clearing Techniques. The next scenario is to understand the impact of different land clearing technique. The first is “slash and burn” technique and the second is “non-burn” technique.

From the result, it can be concluded that slash and burn technique will increase the total impacts compared to non-burn technique.

4. Conclusion

From the LCA calculation model developed in this research, it can be concluded that the plantation is a business unit that accounted for the largest impact followed by the biodiesel factory, and CPO factory. From nine impacts that are assessed, there are 3 dominant impacts that contribute to total impact, namely climate change, photo-oxidant formation, and eutrophication. Differences in the land clearing rate of land in same total area will not affect the total environment impact significantly, since in LCA, total impact on the environment linearly correlate. This is true when using the same input of other input such as the land productivity class, land type, land clearing technique. Land clearing techniques with the slash and burn techniques will result greater environment impact, compared with non burn techniques. The best scenario for a minimal environment impact is by choosing non burn technique as the land clearing technique and the selection of forestland instead of peat-land. Scenario of land productivity class, total area and land clearing rate cannot be used as input for consideration of best scenario because the land area and land productivity class are linearly correlated to the calculation of impacts.

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