Cradle to Gate Life Cycle Assessment of Palm Oil Industry

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Abstract. Crude palm oil production Indonesia especially in Aceh every year continues to increase because the consumption of its derivative products such as cosmetics, food and fuel increases. The increasing demand for CPO has caused palm oil companies expanding their plantations. Based on data from the Ministry of Agriculture in 2018, the total area of Indonesian palm oil reaches 14.3 million hectares. The focus of this paper aims to evaluate the cradle to gate impact produced at land preparation, the nursery stage and the process of producing palm oil. Life cycle assessment is used to evaluate the impact of product for its entire life cycle. This research was conducted with simulation using SimaPro 9.0 software and impact 2002+ method. The results of the data processing with the simulation showed that fertilization stage was the stage with the largest impact with percentage 83% of the category, namely human health, ecosystem quality, climate change and resources 0.0000567 DALY, 9.44 PDF.m².year, 148 kg CO₂ eq and 1650 main MJ, respectively. Meanwhile, the processing of palm oil into CPO the largest environmental impact was in the category of non-renewable energy and global warming of 90 MJ and 9.6 kg CO₂ eq.

1. Introduction
Palm oil is one of Indonesia's mainstay commodities whose development is very fast and occupies important position in the plantation and agriculture sector because it is considered a good investment opportunity for the country's economic growth. Aceh is a province with fairly rapid development of the plantation sector, especially palm oil. At the end of 2018, palm oil plantations in Aceh reached 26,660 hectares with volume of production capacity of 95,234 metric ton [1]. Every year, the development of the Aceh palm oil industry continues to increase, as well as world market demand for CPO. The estimated world demand for CPO in 2025 is 218,300 million tons [2]. This shows that the future the Indonesian palm oil industry, including in Aceh, has the potential to continue to grow in order to meet the world's CPO needs.
Rapid development in the palm oil industry cannot be separated from various problems, negative issues and adverse environmental impacts among others as the cause of climate change [3], increasing greenhouse gases [4], deforestation, conversion of peatland and decreasing of biodiversity [5]. This led the European Union boycotted Indonesian palm oil products so that the impact on Indonesian palm oil exports was rejected by the European Union arguing that Indonesian palm oil is not environmentally friendly.

The palm oil industry consists of several stages, including land clearing, nursery, planting, fertilization, protection, harvesting and processing of fresh fruit bunch (FFB). These stages have their own environmental impact because in the process they use chemicals that have negative impact on environment, including human health, ecosystem quality, climate change and resources. Al Hakim et al reported that the largest source of emissions in palm oil nurseries is the use of diesel, which is 65.5%, where the use of diesel is used as fuel to operate a water pump twice a day followed by the use of fertilizer of 33.6% [6]. Research conducted by Aziz and Hanafiah showed that changes in fertilizer input, transportation and use of diesel in the palm oil industry had an effect on characterization results when compared to the basic scenario. The impact contribution of the alternative scenarios decreased by 2%-5% [7].

One of the popular methods used to calculate energy, environmental impacts and costs arising from the product life cycle stages from the production cycle to waste handling is the Life Cycle Assessment (LCA). Life Cycle Assessment can assess and ensure the sustainability of production through comprehensive assessment and holistic approach so that it is able to provide accurate information that can be applied to environmental management, especially palm oil industry in Aceh [8]. In the data processing stage in this study, the SimaPro software was used. This software is chosen because its flexible and can be used in multi-user-versions [9].

2. Materials and Methods

2.1. Goal and scope, process unit, functional unit and boundary system

In this paper, the focus chosen an approach cradle to gate on the processing of FFB, including land clearing, seedling, planting, fertilizing, protection, harvesting and processing of FFB at palm oil mills. The goal of this paper focuses on evaluating the environmental impacts of the Aceh palm oil industry. The functional unit used is one ton of FFB. In Figure 1 shows the boundary system in the study.
2.2 Analysis method
SimaPro is a software that can determine the sustainability of a product by evaluating the environmental impact of the product's inventory data. In this paper, SimaPro is used to analyse inventory data in the Aceh palm oil industry. Life cycle impact category indicators were calculated using Impact 2002+. Impact 2002+ evaluates 15 different impact categories at the midpoint level namely carcinogens, non-carcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion, respiratory organics, aquatic eco-toxicity, terrestrial eco-toxicity, terrestrial acidification / nutrification, land occupation, aquatic acidification, aquatic eutrophication, global warming, non-renewable energy, mineral extraction. The impact category is then divided into four damage assessment categories, namely human health, ecosystem quality, climate change and resources. The division of the 15 impact categories at the midpoint level based on the damage assessment categories can be seen in Table 1.

Table 1. Impact categories in Impact 2002+.

| Impact Category          | Midpoint Category                              | Damage Unit     |
|--------------------------|------------------------------------------------|-----------------|
| Human Health             | Carcinogens                                    | DALY            |
|                          | Non-Carcinogens                                 |                 |
|                          | Respiratory Inorganics                          |                 |
|                          | Ionizing Radiation                             |                 |
|                          | Ozone Layer Depletion                           |                 |
|                          | Respiratory Organics                            |                 |
| Ecosystem Quality        | Aquatic Ecotoxicity                             | PDF.m².year     |
|                          | Terrestrial Ecotoxicity                         |                 |
|                          | Terrestrial Acidification/Nutrification         |                 |
|                          | Land Occupation                                 |                 |
|                          | Aquatic Acidification                           |                 |
|                          | Aquatic Eutrophication                          |                 |
| Climate Change           | Global Warming                                  | kg CO₂ eq       |
| Resources                | Non-Renewable Energy                            | MJ Primary      |
|                          | Mineral Extraction                              |                 |

Several damage units to estimate the damage of which is DALY, PDF.m².year, kg CO₂ eq and MJ Primary. DALY (Disability-Adjusted Life Years) is person received measure of the overall burden of disease expressed as the number of years lost due to premature death or health problems. PDF.m².year (Potentially Disappeared Fraction) is the part of a species / ecosystem that potential to be lost per m² .per year. Kg CO₂ eq is a unit to determine the effect resulting from an activity that has an impact on global climate. MJ Primary is the basic amount of energy needed to extract natural resources [10].

2.3 Life cycle inventory
Inventory data comes from the Aceh palm oil industry. The amount of material and energy is important part of the inventory data that will be analysed its impact on the environment. The data obtained came from questionnaires, scientific journals, and SimaPro 9.0 database. Primary data were obtained from several palm oil plantations and mills that represented the Aceh palm oil industry. General information such as description of the process, the input and output of the boiler emissions and generator and the amount of POME generated from palm oil obtained based on the questionnaire that was developed based on ISO 14041 [11]. Interview directly with the head of the mill was also performed to validate the data obtained by agricultural practices and mills operations.
Table 2. Life cycle inventory in Aceh palm oil industry per ton of FFB.

| No | Process | Mass and Energy | Amount |
|----|---------|----------------|--------|
| 1  | Land Clearing | Herbicide (kg) | 0.16359 |
|    |         | Diesel (L) | 0.13357 |
| 2  | Seedling | Fungicide (kg) | 0.14706 |
|    |         | Insecticide (kg) | 0.01007 |
|    |         | Pesticide (kg) | 0.03477 |
|    |         | Meister of Fertilizer (kg) | 0.01539 |
|    |         | Urea/Sulfonylecurea (L) | 0.21337 |
|    |         | P₂O₅ (kg) | 0.02033 |
|    |         | Muriate Photash (kg) | 0.00019 |
|    |         | Dolomite (kg) | 0.00038 |
|    |         | NPK (kg) | 0.11742 |
|    |         | Electricity (kWh) | 5.07301 |
|    |         | Diesel (L) | 0.93024 |
| 3  | Planting | TSP/SP36 (kg) | 1.8316 |
|    |         | Rock Phosphate (kg) | 0.23123 |
| 4  | Fertilizing | ZA (kg) | 26.2709 |
|    |         | ZA-Edta (kg) | 0.04754 |
|    |         | HGFBorate (kg) | 0.01636 |
|    |         | Rock Phosphate (kg) | 24.2835 |
|    |         | Cu-Edta (kg) | 0.05371 |
|    |         | Kieserit (kg) | 20.5037 |
|    |         | NPK (kg) | 86.4924 |
|    |         | HGFB (kg) | 0.44204 |
| 5  | Protection | Isopropyl Amine Glicosphate (L) | 0.16052 |
|    |         | Paraquat Dichloride (L) | 0.20589 |
|    |         | Troclopir (L) | 0.01451 |
|    |         | Florosipir (L) | 0.03025 |
|    |         | MethylMetsulfuron (kg) | 0.00633 |
|    |         | Fipronil (L) | 0.00247 |
|    |         | Polydor 25EC (L) | 0.00062 |
|    |         | Dipel (Bacillus thuringiensis) (L) | 0.0247 |
|    |         | Thuricide HO (kg) | 0.00154 |
|    |         | Pesticide (kg) | 0.36404 |
| 6  | Palm Oil Mill | Diesel (L) | 1.63584 |
|    |         | CPO (kg) | 202.7972 |
|    |         | Steam Consumption (kg) | 11.3563 |
|    |         | Palm Kernel (kg) | 97.9021 |
|    |         | Empty Fruit Bunch (kg) | 160.8392 |
|    |         | POME (kg) | 699.3 |
|    |         | Fibre (kg) | 97.9021 |

Land clearing is carried out with manual and semi-mechanical systems so that soil fertility is not damaged and is well preserved. Land clearing requires a lot of worker in short time and incidental. Therefore, the implementation of this work is given to contractors who are experienced in preparing land clearing until the land is ready for planting. The Seedling stage begins when the sprouts are planted in small polybags. After 90 days, the grown seedlings are transferred to large polybags and waited for
225 days to become mature palms. This stage requires fertilizer, herbicide and fungicide as its application. After the seeds are ready, they will enter the planting stage. At the planting stage, a planting hole is made a few days before planting with size of 50×40 cm and depth of 40 cm. The excavated top soil with thickness of 20 cm is separated from the bottom soil. The time chosen for planting is during the rainy season. This is intended to provide sufficient water for seeds to grow well. Palm oil cultivation only hopes for rainfall because there is no irrigation in Aceh's oil palm plantations. Fertilization is done according recommendation of the plantation RND team. The types of fertilizers used are inorganic fertilizers namely NPK, ZA, HGF Borate, Rock Phosphate, Cu-Edta, Kieserit and HGFB. Fertilization is not done when the rain intensity is high because it reduces water pollution by fertilizers. Meanwhile, protection is carried out manually and chemically according predetermined rotation of 6-12 rotations/year. After three years, the palm oil is ready to be harvested and delivered to the palm oil mill to process for CPO. In palm oil mills, FFB is weighed and sorted according to ripeness of the fruit. The selected fruit is ripe right. The sorted FFB then goes into the sterilization and pressing stages to extract crude palm oil. At the oil pressing stage, fibre is formed which can be used as boiler fuel. Nut that is generated from the pressing stage has to be separated in order to be cracked so that palm kernel in it obtained. Emissions generated from palm oil mills are SO₂, NO₂, NH₃, HCl, HF and particulates from boilers and generators used in palm oil mills and POME is wastewater that can be used as methane gas producer.

3. **Result and Discussion**

Life cycle impact assessment aims to evaluate the impact of an activity/process carried out. Potential impacts were determined using the results from inventory data analysis. The inventory data obtained were analysed by translating all relevant outputs and emissions into environmental impact score. In this paper, evaluation of the environmental impact of plantation activities and palm oil mills was carried out. The results of data processing using SimaPro software in analysis of the impact of palm plantation activities can be seen in Figure 2, Figure 3 and Table 3. Meanwhile, the analysis of the impact of palm oil mill activities can be seen in Table 4.

![Figure 2](image.png)

**Figure 2.** Damage assessment of six stages in palm oil plantations.
Figure 2 shows that the largest percentage is generated on the impact of resources, namely greater than 80% at each stage. This is due to the use of non-renewable energy sources such as natural gas, coal and petroleum in the manufacturing process of chemicals for palm plantation applications [12]. While the smallest impact was obtained in the category of impacts on human health and ecosystem quality, but at the protection stage, percentage of impact on ecosystem quality was the highest among other stages. This is because the use of pesticides and herbicides at the protection stage not only kills the pests that exist in palm oil plants but can also disrupt the ecosystem in the soil and water [13]. Pests can reduce the productivity of oil palm plants by 20-22%. But the use of pesticides and herbicides to certain extent can increase soil erosion, reducing organic matter, increasing pest resistance to pesticides and herbicides. The impact of ecosystem quality and climate change is very influential on the impact of resources [14]. The use of chemical fertilizers in the fertilization stage provides the highest impact resources with value of 1650 MJ primary.

![Graph showing relative contribution of each stage for each impact category.](image)

**Figure 3.** Midpoint damage assessment in palm oil plantations.

At the midpoint level, the impact results are given in different units. Materials entered in ton are converted into emission-based impact categories. Figure 3 shows the relative contribution of each stage for each impact category. From this figure, it can be seen that the most dominant impacts are the stages of fertilization, protection and seeding and land clearing. This is because the use of inorganic fertilizers from N fertilizers, pesticides, herbicides and insecticides is the biggest contributor to the impact of the plantation stage [15] [16]. Research conducted by Hidayatno found that land clearing using non-burning techniques can reduce environmental impacts and selecting forest as land for palm oil plantations is also better than using peatlands [17]. Globally, peatlands store around 329-525 giga tons of carbon and around 14% are in the tropics. This large carbon stock also causes the high amount of carbon released into the atmosphere when peatlands are burned during line clearing [18].
Table 3. Damage assessment of six stages in oil palm plantations.

| Kategori Dampak       | Unit       | Land Clearing | Seedling | Planting | Fertilizing | Protection | Harvesting |
|-----------------------|------------|---------------|----------|----------|-------------|------------|------------|
| Human Health          | DALY       | 1.16×10⁻⁶     | 9.17×10⁻⁶ | 1.93×10⁻⁶ | 5.67×10⁻⁵  | 2.93×10⁻⁶  | 3.6×10⁻⁶   |
| Ecosystem Quality     | PDF.m².year | 0.457         | 1.57     | 9.75×10⁻⁴ | 9.44        | 10.3       | 0.183      |
| Climate Change        | kg CO₂ eq  | 1.83          | 11.4     | 0.0187   | 148         | 3.67       | 3.50       |
| Resources             | MJ Primary | 32.5          | 192      | 0.277    | 1650        | 69         | 51.9       |

Based on Table 3, it is known that the stage that has the greatest impact from each impact category is the fertilization stage. This stage is the main contributor to the impact category on oil palm plantations, accounting for 83% of the total impact. This fertilization stage has impact categories, namely human health, ecosystem quality, climate change and resources with respective values of 0.0000567 DALY, 9.44 PDF.m².year, 9.44 CO₂ eq and 1650 MJ primary. Meanwhile, the other five stages only have value of up to 9.17×10⁻⁶ DALY, 9.3 PDF.m².year, 11.4 CO₂ eq, and 192 MJ primary.

For human health impact units, the scale of damage for DALY has range of values from 0 ≤ DALY ≤ 1, where the closer to 0, the smaller the impact on humans. The resulting human health impact is very small and can be ignored. Research conducted by Siregar et al. found that the fertilization stage produced the highest contribution when compared to other plantation stages [19]. Similar results were also reported by Zulkifli et al., the use of N fertilizer and N fertilizer production were the biggest contributors to the impact in the production of fresh fruit bunches for processing CPO in palm oil mills [20].

Table 4. Damage assessment of palm oil mills.

| Midpoint Category            | Unit       | Amount     |
|------------------------------|------------|------------|
| Carcinogens                  | DALY       | 2.75×10⁻⁸  |
| Non-Carcinogens              | DALY       | 1.12×10⁻⁷  |
| Respiratory Inorganics       | DALY       | 2.97×10⁻³  |
| Ionizing Radiation           | DALY       | 1.97×10⁻⁹  |
| Ozone Layer Depletion        | DALY       | 8.96×10⁻¹¹ |
| Respiratory Organics         | DALY       | 6.59×10⁻⁹  |
| Aquatic Ecotoxicity          | PDF.m².year| 2.51×10⁻⁴  |
| Terrestrial Ecotoxicity      | PDF.m².year| 3.80×10⁻²  |
| Terrestrial Acidification/Nutrification | PDF.m².year | 1.78 |
| Global Warming               | kg CO₂ eq  | 9.6        |
| Non-Renewable Energy         | MJ primary | 90         |
| Mineral Extraction           | MJ primary | 0.0242     |

Based on Table 4, it can be seen that the most influential impact of palm oil mills is on non-renewable energy and global warming with the respective value of 90 MJ and 9.6 kg of CO₂ eq. The use of diesel fuel in generators and boilers in generating electricity for palm oil mills is the cause of the high impact of these two categories. In the research conducted by Shafie et al., the use of non-renewable fuels such as diesel is the key variable in the high impact of global warming and non-renewable energy [21]. Similar results were also shown in the research of Kaewmai et al., the use of fossil fuels in energy fulfilment palm oil mills is the highest contributor to global warming [22]. Midpoint categories that are
quite influential on palm oil mills are aquatic eco-toxicity and terrestrial eco-toxicity, the values were 2.51x10^4 dan 3.80x10^2 respectively. PDF units show potentially lost species / ecosystems calculated in m²·year units. This means that the higher the value of PDF, the greater the potential for species / ecosystems to be lost.

4. Conclusion
In oil palm plantations, fertilization stage was the stage with the largest impact with percentage of 83% of the category, namely human health, ecosystem quality, climate change and resources 0.0000567 DALY, 9.44 PDF.m².year, 148 kg CO₂ eq and 1650 main MJ respectively. Meanwhile, the processing of palm oil into CPO, the largest environmental impact was in the category of non-renewable energy and global warming of 90 MJ and 9.6 kg CO₂ eq. The use of diesel fuel in generators and boilers in generating electricity for palm oil mills is the cause of the high impact of these two categories.

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