Review of Implementation Life Cycle Assessment for Biodiesel Production from Palm Oil (*Elaeis guineensis* Jacq.) in Indonesia

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Abstract. Palm oil has benefits for economic and social development in Indonesia. However, palm oil is faced by several environmental problems most of them due to the land conversion from forest to the palm plantation. Therefore, numerous greenhouse gas emissions and other environmental effects also emitted during palm oil and biodiesel production. The life cycle assessment (LCA) method can be used for the evaluation of the palm oil production process impact on the environment as well as for potentially reducing the hotspot. A literature study was used in the identification of the implementation of LCA for biodiesel from palm oil in Indonesia. Study cradle to grave LCA for biodiesel production in Indonesia was still limited. Gate to gate and cradle to gate system boundary was the major boundary system used in the identification of the environmental effect for biodiesel production in Indonesia. However, numerous study has applied that boundary system and various scenario has been proposed in reducing the environmental effect for biodiesel production. Limitation of the LCA boundary for palm oil production is needed to be enhanced as well. Robust life cycle inventory in a wider range (i.e., cradle to grave) will be needed in order to present this industry in a global forum.
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1 Introduction

Out of all kinds of plant-based oil in the world, palm oil (*Elaeis guineensis* Jacq) is favored as the most-produced commodity as well as the most consumed one. Being cheap, production-efficient, and highly durable are qualities that allow it to be used in not only a wide assortment of food, cosmetic, and hygiene products, but also a reliable source for biofuel or biodiesel. As oil palm trees require constant warm weather, sunlight, and plenty of rain for maximum production, they are generally cultivated in Asia, Africa, and South America. [1]

Contributing to approximately half of the global commodity, Indonesia holds the record as the world's number one producer of palm oil [2, 3]. Along with Malaysia, the two countries are accounted for more than 80 % of global production [4]. In 2014, Indonesia produced 32.5×10^6 of Crude Palm Oil (CPO) and exported 80 % of it, earning USD 18.6×10^9 [1]. Palm oil is the largest agricultural industry in Indonesia [1], and its production is expected to continue to expand at 10 % yr^{-1} [5]. The total amount of harvested palm oil area throughout Indonesia has grown from 4.1×10^6 ha in 2006 [4] to an estimated 8.9×10^6 ha in 2015 [6], and is projected to reach 17×10^6 ha by 2025 [7]. The area with the highest percentage of yield is affirmed to be Sumatra Island – covering 80 % of total production – followed by Kalimantan at 17 % and Sulawesi at 2 % [8].

Palm oil-based biodiesel production is challenged by scores of environmental issues, which may occur from emission release – known as carbon footprint – during palm oil development. In palm oil industry, there are two components of carbon footprint: emission from deforestation and emission from palm oil processing. Specifically in palm oil processing, fossil fuel inputs are necessary for operating mechanized plantation equipment, applying chemical fertilizer, transporting goods, and running industrial processing [9, 10] Margono [11] discovered that in palm oil production, deforestation and land conversion were the main emission factors, while palm oil mill effluent (POME) and fertilizer application were hand-in-hand to be the second ones. European and American countries claim that palm oil biodiesel throw carbon emission in the atmosphere along its production path.

Furthermore, US EPA-NODA and EU RED stated that palm oil-based biodiesel could reduce the emission of GWP by only 17 % to 19 % compared to fossil-based fuel [12]. Considering the minimum requirement of 20 % in the USA and 35 % in the EU, it is difficult for Indonesia's CPO to penetrate the global market. Further investigation is therefore essential to respond to the issues and, at the same time, prove that biodiesel from Indonesia is environmentally friendly. A method in quantifying the amount of emission in biodiesel production is needed, and Life Cycle Assessment (LCA) has been the chosen approach despite the fact that its implementation nationwide is limited when compared to other countries like Malaysia or Thailand [13].

LCA is characterized as a scheme to measure the inputs and outputs of a product system as well as its potential environmental impacts throughout its life cycle. Various industries have been employing this ISO 14040 and 14044-standardized scheme to communicate their products' environmental performances [14, 15]. Focusing on environmental impacts of a product or service, points evaluated are raw material absorption, provision, product usage, and final disposal. LCA is also relevant for detecting how much emission released during land-use change. The results strongly depend on the reliability and adequacy of data inventory of the assessed object, so data collecting is vital; it should be the focal point in applying LCA as it is the most time-consuming process [8]. In the case of Indonesia, only very limited data is accessible. Even though it is necessary to counter environmental issues entailing Indonesia's palm oil biodiesel development, this research aims to review LCA implementation in palm oil biodiesel production in Indonesia.

2 Method

The methodology used is mainly literature study toward research findings representing LCA implementation in biodiesel production and development. The literature has been compiled from a selection of sources for the purpose of not only investigating environmental issues led by palm oil-based biodiesel production in Indonesia, but also indentifying the current status of LCA implementation. Further, this study is also expected to be able to capture the extent of LCA implementation in addressing environmental issues concerning palm oil development in Indonesia.

3 Result and discussion

3.1 The benefit and importance of palm oil production in Indonesia

Energy is always important in life, as it plays a significant role in supporting national activities for social, economic, and environmental achievements. In Indonesia, energy consumption has been increasing rapidly as a simultaneous effect of economic and population growth, causing it a fundamental need in the future. Currently, the nation is very much dependent on fossil fuel as the main energy source, while attempts on utilizing renewable non-fossil energy as an alternative has not been implemented optimally. Data says that the nation's fossil oil reserve is approximately 9×10^9 barrels; with average production rate of 500×10^6 barrel yr $^{-1}$, the reserve will be exhausted in 18 yr. Indonesia's petroleum production has presently decreased due to declining number of natural reserves and increasing number of depleted ones. The government has been importing both crude oil and petrol to meet domestic consumption. Since fuel is subsidized while its price increases from time to time, crude oil is always influential toward the nation's ability to provide the budget. That petroleum is still the major energy source for electricity power, industry, and transportation puts another concern on securing fuel supply. In the midst of the crisis, the thought on energy diversification arises. After attempts made to find alternative energy sources able to substitute petroleum and other conventional energy bases as well as to cover national demands, palm oil is considered the most promising out of all candidates.

Regarding production, Indonesia has already been on the lead quantitatively. The agricultural product export rate was 7.8 % in 1980 and grew to be 9.4 % in 1990; in 2011, when around 51 % of the merchandise was of palm oil products, the rate became more than doubled to 20.9 %. Considering how palm oil products were only 1.6 % of all commodities in 1990 and 2.5 % in 2000 before shooting up to 10.6 % in 2011 [16], it is conclusive that palm oil is a popular crop and is substantial in generating national income. As to development, its derivative products are potential to be energy sources. Palm oil biodiesel is compatible to replace solar fuel. Its post-harvest biomass waste (frond, trunk, mesocarp fibers, palm kernel shell, empty fruit bunch (EFB), and POME) is an abundant source of biogas, which is a good means for methane capture in milling process [17]. Its post-extraction waste is also suitable for producing biomass to generate electricity power [10].

Ahrens, Drescher-Hartung, and Anne stated that the process of transforming into advanced biofuels with low emission rate of greenhouse gases should be regarded as a cost-effective manner [18]. Biodiesel production and consumption will provide a significant role in generating jobs and maintaining economic growth, since they should involve farmers and other small-scale enterprises in their value chains. Plants needed as raw materials should help to improve the soil's environmental condition if cultivated on 'marginal' soil. Biodiesel utilization should also secure the availability of domestic knowledge and skills important to set up its own development capacity all the way from raw material, manufacturing, to distribution. However, some challenges must be addressed in order to maximize all benefits of utilizing biodiesel fuel, regarding i.e. the most effective raw materials, sustainable raw material supply, reliable production process, biodiesel fuel specification, pricing policy, fiscal policy, and – more importantly – environmental impacts.

3.2 The environmental effect of palm oil production

While being important in nourishing economic growth and increasing public welfare in Indonesia, palm oil industry is always challenged by a number of national and international Non-governmental Organizations (NGOs) regarding environmental problems. One issue is about carbon emission out of palm oil production, and the other is about ecosystem disturbances due to land-use change from forest to palm oil plants. The confrontation is so massive that the EU and the USA pay extra heed to these matters in regards of global warming.

Oil palm plantations in Indonesia are not only developed on mineral soils but also on peatlands, which are mainly found in provinces of Riau, Jambi, West Kalimantan, and Central Kalimantan. Some peatlands are indeed suitable for oil palm. Since Indonesia is already declared to be the third-largest CO_2 emitter in the world, mostly instigated from agriculture, forestry, and peatland uses for other uses [19, 20], developing them means facing numerous threats. The first and greatest one is carbon emission due to both land clearing – which usually involve land burning – and peat decomposition. Oil palm tree cultivation also emits excess of greenhouse gas (GHG) and air pollutants along its series of process as a result of forest clearing, machine usage, transportation, and palm oil handling as well as its effluent. POME itself produces about 10^3 of methane t^{-1} [21]. Siregar et al [13] has shown in his study that biodiesel potentially throws 2 568.82 kg CO2eq t^{-1}-BDF (Biodiesel Fuel) to GHG emission during fertilizing process, contributing 35.15 % in total.

In spite of its significant GHG emission, palm oil can actually be concluded as carbon neutral. It is after discovery of the fact that oil palm trees are able to absorb harmful GHG emission better than rainforest trees, which means oil palm trees can serve as more efficient carbon sink. According to a study conducted by Sumanthi et al. [22], oil palm farm assimilate 44 t of dry matter ha^{-1} yr^{-1}, which is higher than 25.7 t original rainforest does. It should allow a number of mitigation plans to run concurrently in order to secure carbon balance in biodiesel production, e.g. application of organic fertilizer and cultivation on only degraded lands or lands with low biomass accumulation. Further, biochar production can be performed when replanting process starts [23].

3.3 Implementation of LCA approach for palm oil biodiesel production in Indonesia

In measuring any impacts toward environment that may occur when a commodity exists, both material consumption and waste discharge throughout its life cycle – raw material sourcing, manufacturing, distribution, consumer use and disposal – need to be quantified and evaluated. LCA acts functionally as a tool for comparing products of equal function aiming to select one(s) with the least damage risk. Further, it is able to support decision making in enterprises or government in the attempt of environmental improvement.

As a series of industrial process, biodiesel production undoubtedly affects the environment. Environmental impact assessment toward it is therefore critical to reduce environmental damages and to ensure sustainable production of biodiesel. LCA has been implemented for the purpose by researchers, meeting ISO 14040 and 14044 standards to cover activities of (i) defining goal and scope, (ii) listing life-cycle, (iii) assessing impacts along life-cycle, and (iv) interpreting the results. Until the moment this paper is written, researches ever performed in Indonesia on above matter are limited to cradle-to-gate and gate-to-gate analyses. Some of the results on cradle-to-gate analysis are as listed [13, 24–28]. Specifically on palm oil biodiesel production, points studied are the flow from oil palm plantation to CPO production to biodiesel manufacturing in palm oil mill.

Cradle-to-gate analysis by comparing palm oil biodiesel to *Jatropha curcas* oil biodiesel has been conducted by Siregar et al. [13] and Nazir and Setyaningsih [24]. Referring to ECO indicator 99, study [24] stated that palm oil biodiesel production leads to more significant GHG emissions (at 320 mPt) and, therefore, creates more impact environmentally than jatropha oil (at 110 pt) by 66 %. Employing centre of environmental science (CML) method, study [13] came with similar result. Further details on the latter study are as follow:

(i). Five environmental categories known as Global Warming Potential (GWP) were considered. They are acidification, waste for landfill volume, euthropication, and energy consumption.
(ii). Total environment impacts before and after stable productivity period were identified.
(iii). It was concluded that GWP is equally significant to impact the environment when biodiesel is produced from either palm oil or jatropha oil.
(iv). Agrochemical utilization in the form of fertilizer and plant protection also contributes significantly to the impact by 50.46 % for palm oil and 33.51 % for jatropha oil.
(v). GWP before stable productivity period was recorded to be 1 695.36 kg CO_2eq t^{-1}-BDF and 740.90 kg CO_2eq t^{-1}-BDF for palm oil and jatropha oil, respectively. GWP after stable productivity period was decreased up to 37.83 % and 63.61 % for palm oil and jatropha oil, respectively.

Although jatropha oil is more promising, its development is constrained since cultivars with superior and stable productivity are not available [29–31].

Soraya et al. [25] directed LCA in its cradle-to-gate analysis to biodiesel production in Indonesia. Basing the study to environmental parameters – GWP, photochemical oxidation acidification, euthropication potential, and abiotic resource depletions – two scenarios were delivered toward CPO production: (i) palm oil manufacturing without biogas recovery, in which POME from FFB's sterilizer was sent to wastewater treatment pond, and (ii) palm oil manufacturing with biogas recovery, in which POME was sent to wastewater treatment pond and digested by anaerobic bacteria for methane capture. Below are the results:

(i). On GWP, scenario (i) found that 1 t biodiesel production emitted 690.7 kg CO_2eq, 58 % of which came from cultivation stage while 16 % was from CPO production and 26 % was from biodiesel production. From scenario (ii), the rate was 28 kg CO_2eq, which was lower from the other scenario at 112 kg CO_2eq. It is apparent that biogas capture utilized as electricity power source makes a big difference on the amount of GHG emission.
(ii). On photochemical oxidation, scenario (i) revealed that 1 t biodiesel production emitted 0.563 kg CO_2eq. Biogas utilization in scenario (ii) helped to reduce CH_4 emission, allowing a decrease to 0.394 kg CO_2eq t^{-1}-BDF.
(iii). On acidification, scenario (i) noted a total amount of 5.175 kg SO_2eq. In scenario (ii), more than 50 % came from cultivation stage while its CPO production was 0.354 kg SO_2eq, lower than the other at 1.178 kg SO_2eq.
(iv). On eutrophication, the outcome was 1.145 kg PO_4eq t^{-1}-BDF and 1.008 kg PO_4eq t^{-1}-BDF for scenario (i) and scenario (ii), respectively.

Rosmeika et al. [28] tried LCA to compare conventional biodiesel production to the one using superheated methanol vapor (SMV) technology in its cradle-to-gate analysis. Mainly aimed to find out whether energy consumption and environmental impacts of CPO-based biodiesel production should differ by employing catalytic method to non-catalytic (SMV) one, the study's impact analysis was limited to GHG emission, acidification, eutrophication, and energy consumption. It is then revealed that biomass waste utilization as a substitute of fossil fuel should generally be able to reduce both total energy consumption and environmental impacts in both methods. Implementation of methane capture system in palm oil mill significantly influences GHG saving attempts. When methane capture system is run along with biomass waste energy sourcing system in a biodiesel plant, GHG reduction works best in SMV method. Consequently, this study suggested SMV to be made feasible while generating biomass waste power along biodiesel production line.

Wahyono et al. [26] focused the study on energy balance. Also referring to LCA, cradle-to-grave analysis has been applied to calculate energy inputs and energy outputs of biodiesel production in Banyuasin, Indonesia, covering oil palm tree plantation, palm oil milling, and biodiesel manufacturing. The finding was that un-renewable fossil energy sources were the largest energy input in all three steps of production. In plantation, the most energy input was for urea application as fertilizer. In milling, it was for electricity power. In biodiesel manufacturing, it was for methanol production. Since the values of NEB and NER were positive, the product of the aforementioned area is considered feasible to operate. The final sum showed that energy surplus occurred from the production process. Conclusively, biodiesel production in terms of palm oil is sustainable.

All these LCA-based studies on biodiesel production had been carried on in respond to censures regarding environmental issues caused by palm oil industry in Indonesia. Detailed and critical LCA approach should be effective for Indonesia in devising sound arguments to support palm oil production. Further, LCA should be helpful for the industry in spotting any environmental burdens as well as in finding good recommendations to improve the production's sustainability.

3.4 Sustainability of palm oil production

LCA-based studies have been recognized by palm oil stakeholders in both upstream and downstream directions. Government-owned plantation companies are currently in such deep concerns on the production sustainability that biomass power plant installation and LCA implementation are planned in the industry's roadmap. The next required strategy is to develop the industry's capabilities and to advance its production sustainability to all directions in order to provide more competitive palm oil products in global market.

The framework for sustainable palm oil production has been devised after campaigns launched by NGOs concerning environmental impacts that took much attention to stakeholders. Sustainability standards and certification schemes in palm oil sector was designed and introduced. In 2004, the Roundtable on Sustainable Palm Oil (RSPO) was formed by a collection of industry representatives and civil society groups to watch over the implementation process [32]. It promotes sustainable palm oil growth and use based on certain criteria as well as provides incentives for companies and producers capable of improving their practices. RSPO criteria comprise economic, social, and environmental aspects of palm oil plantation development, management, and production. Indonesia has been running ISPO since its initiation in late 2009 after CPO purchase-contract cancellation was committed by a number of consumer-product companies due to deforestation concerns. Not like RSPO, ISPO was established to be obligatory standard to cover all palm oil growers in the nation, consisting of seven principles of development [33].

Implementation of LCA as a sustainability factor for PROPER (*Program Penilaian Peringkat Kinerja Perusahaan dalam Pengelolaan Lingkungan Hidup* - Company Performance Rating Program in Environmental Management) mechanism has been after

ISO standards. A policy of the Ministry or Environment and Forestry represented in a rule of the DITJEN PPKL (*Direktorat Jenderal Pengendalian Pencemaran dan Kerusakan Lingkungan* – Directorate General of Pollution and Environmental Damage Controls) dictates that it should be adopted in PROPER criteria in near future.

4 Conclusions

LCA is widely accepted and ISO standardized due to its being extensive and thorough in registering chances of environmental problems that may occur due to the existence of a certain production activity. Scientists, stakeholders, and societies are in unison that although products and energy are important in life, environmental degradation should be avoided at all cost. Palm oil, one of the biggest industries in Indonesia, is so far proven to be the most viable source of renewable energy. Any disputes regarding environmental impacts should be starting points to prove that palm oil products are environmentally friendly; when refer to LCA, global societies should be convinced. Since the key to this advantageous opportunity lies in inventory database, stakeholders of palm oil sector – especially the government – should put extra attention to solve this particular challenge. Robust life cycle inventory in a broader range (i.e., cradle-to-grave) is essential in presenting the industry in global forum. Once made available, endeavors on securing palm oil produce in global market is expected to be more straightforward.

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