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Conference Paper

Value Chain Analysis of Palm Oil Biodiesel through a Hybrid (ISO-Eco) Life Cycle Assessment Approach

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Abstract

This study assesses the life-cycle impacts of palm oil biodiesel value chain in order to provide insights toward holistic sustainability awareness on the current development of bio-based energy policy. The assessment methodology was performed under a hybrid approach combining ISO-14040 Life Cycle Assessment (ISO-LCA) technique and Ecologically-based Life Cycle Assessment (Eco-LCA) methodology. The scope of this study covers all stages in palm oil biodiesel value chain or is often referred to as "cradle-to-grave" analysis. The functional unit to which all inputs and outputs were calculated is the production of 1 ton of biodiesel. For the analysis, life cycle inventory data were collected from professional databases and from scholarly articles addressing global palm oil supply chains. The inventory analysis yields a linked flow associating the land used, fresh fruit bunch (FFB), crude palm oil (CPO), per functional unit of 1 kg of palm oil biodiesel (POB). The linked flow obtained in the inventory analysis were then normalized and characterized following the characterization model formulated in stocktickerISO-LCA guidelines. The aggregation of ecological inputs was classified based on the mass and energy associated to each unit process in the value chain, which are cultivation, extraction, conversion, and utilization. It is noted that compared to other unit processes, cultivation is the most crucial unit process within the whole palm oil biodiesel value chain. This study serves as a big picture about the current state of palm oil biodiesel value chain, which will be beneficial for further improving oversight of the policy making and service toward sustainable development.

Keywords: Palm oil, biofuel, Life Cycle Assessment, value chain analysis, sustainability

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1. Introduction

Biofuels production pathway through conversion of plant oils into fatty acid methyl ester (FAME) or biodiesel opens an opportunity for economic growth and energy security for producing countries. Among the different plant oil feedstock, palm oil is considered as a potential feedstock due to its high oil content and yield [1,2]. However, concerns over environmental and social impacts related to production of palm oil have been rising [3,4].

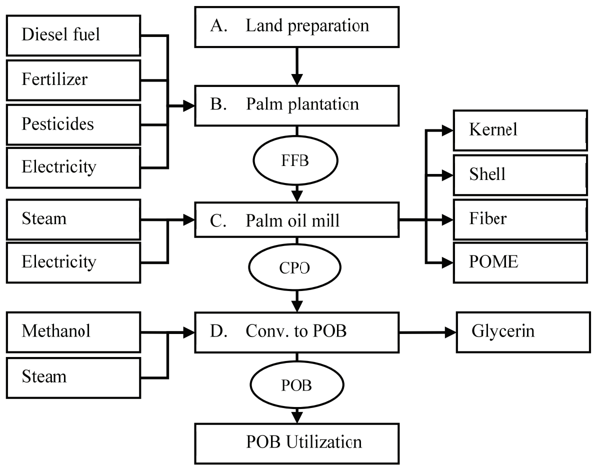

Figure 1: Process Flow Diagram of Palm Oil Biodiesel [16].

Various tools and methodologies for assessing and benchmarking environmental impacts of different product system have been developed and implemented. In order to advance the decision making process that favors sustainability at various levels (e.g., policies, regulations and practices), an integrated life cycle sustainability assessment (LCSA) framework has been developed [5,6]. This framework combines the application of the static life cycle analysis with dynamic system modeling and simulation to show the possible evolutionary trajectories of given scenarios.

This study aims to demonstrate the LCSA methodology in the static life cycle analysis part through a novel approach that couples the ISO 14040 Life Cycle Assessment (ISO-LCA) [7] and the Ecologically-based LCA (Eco-LCA) [8] methodologies on a value chain of palm oil biodiesel. By applying this hybrid LCA approach, it is expected that a more comprehensive life analysis can be performed and, thus, it can provide far-reaching information about the sustainability impacts of palm oil biodiesel, which in turns will be useful for decision makers to make well-informed policies.

2. Methodology

For the ISO-LCA, the scope of this study covers all stages in palm oil biodiesel supply chain from land clearing, cultivation, milling and conversion, up to the utilization of biodiesel in vehicles (Fig. 1). The functional unit used in this study is the production of 1 metric ton of palm oil biodiesel (POB). Detailed unit processes and input-output flows referred for the inventory analysis are shown on Fig. 1 which covers material and energy flows on each unit process. The impact assessment uses the standard procedure given in ISO 14040 as well as the guidelines and characterization factors given in the handbook of LCA [9]. Inventory data for this study were collected from secondary and surrogate databases [10,11,12,13,14,15]. Process Flow Diagram of Palm Oil Biodiesel [16]

For the Eco-LCA, the system boundary was extended to include the role of ecosystem goods and services. The biodiesel supply chain here was simplified to a “gate-to-gate” system starting from cultivation and ending at the refining step used for

Impact Category	Quantity	Unit
Land use	0.21	[ha.a]
Global warming	9,415.20	[kg CO_2-eq]
Human toxicity	7.80	[kg 1,4-DCB-eq]
Eco-toxicity (freshwater)	1,771.40	[kg 1,4-DCB-eq]
Eco-toxicity (terrestrial)	244.20	[kg 1,4-DCB-eq]
Photo-oxidant formation	0.20	[kg C_2H_4-eq]
Acidification	10.10	[kg SO_2-eq]
Eutrophication	3.20	[kg PO_4^{3-}-eq]
Abiotic res. Depletion	4.00	[kg Sb-eq]

Table 1: Life Cycle Impact Analysis per ton of POB.

the production of palm oil biodiesel. Similar to the ISO-LCA, the functional unit is one metric ton of POB. A key assumption in the chosen production route is that the production facilities are all located closed to each other, which is reasonable since palm oil biodiesel is typically produced in the same location as the palm oil milling plant and is located in-situ with plantation.

The information flow for material and energy for each process at the economy level was approximated using the most relevant available economic sectors in Economic Input-Output analysis table provided in Eco-LCA website [17]. This table is based on the 1997 491-sector model of the North American Industry Classification System (NAICS) standard. For instance, palm oil cultivation is represented by oilseed farming (NAICS sector 11112) and palm oil extraction by oilseed processing (NAICS sector 311223).

The current Eco-LCA software uses the functional unit of each resource in terms of U.S. economy (i.e., USD) for normalization. Therefore processes that are in the "economy level" need to be converted from their quantities (i.e., kg) in the process LCA-linked-flow to their corresponding prices.

3. Results and Discussions

The accounting of life cycle inventory for ISO-LCA yields a linked-flow described as Eq. 1.

$$0.206\ \text{ha}\cdot\text{y} \rightarrow 5{,}184\ \text{kg}_{\text{FFB}} \rightarrow 1{,}089\ \text{kg}_{\text{CPO}} \rightarrow 1{,}000\ \text{kg}_{\text{BDF}} \tag{1}$$

Using the physical flow, the impact analysis based on the baseline impact categories given in the operational guide the ISO-LCA standard has been obtained and the results are presented in Table 1.

From impact assessment, it is inferred that global warming and eco-toxicity potentials are the main hotspots of palm oil biodiesel value chain. The climate change-related impact is associated with the land clearing process, the combustion of fossil fuels during electricity generation, fertilizer manufacturing and material transportation as well as methane release from anaerobic digestion of palm oil mill effluent (POME).

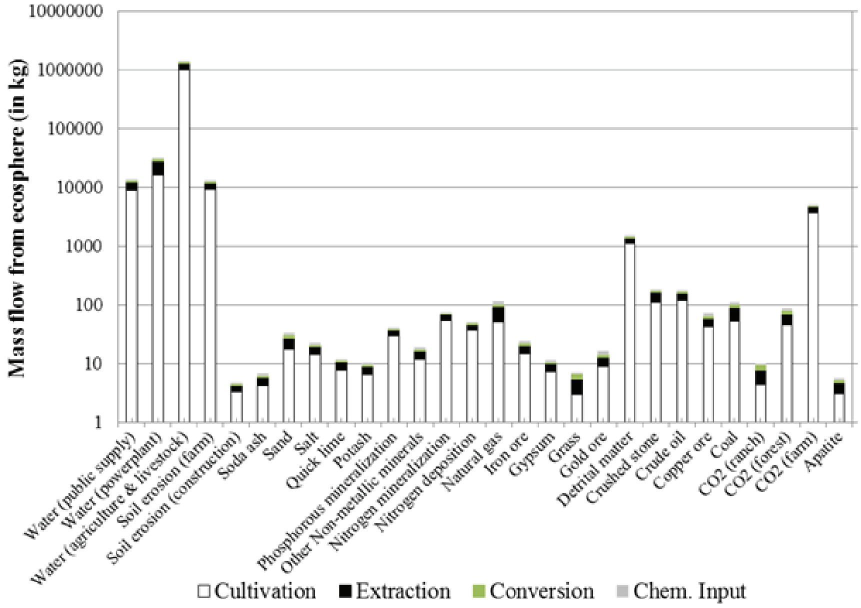

Figure 2: Resource Consumption per ton of POB.

Eutrophication and acidification are other significant impacts of the palm oil biodiesel value chain. These are associated with pesticides and insecticides use in the cultivation stage which are released to the air and waterways and result in potential eutrophication and acidification hazards.

From the Eco-LCA calculation, results show, as expected, the reliance of palm oil biodiesel on the natural capital provided by the ecosystem, including sunlight, carbon dioxide from atmosphere, detrital matter from biosphere, water from hydrosphere, as well as fossil fuels and various form of mineral from lithosphere such as coal, crude oil, natural gas, salt, sand, phosphorous and nitrogenous mineralization (Fig. 2). Although large quantities of ecosystem goods are consumed along the life cycle of palm oil biodiesel, in terms of mass, only a few of them are significant in quantity. Results show that carbon dioxide, detrital matter, fossil fuels, and soil erosion are the ecosystem goods and services that are consumed in the order of more than 100 kg per ton of POB.

Cumulative water inputs account for 1.4×10^3 ton, and CO_2 accounts for 5 tons per ton of POB as a result of water uptake and the process of CO_2 fixation during the photosynthesis associated with the cultivation of oil palm. Detrital matter, which accounts for 1.5 tons per ton of POB, is another significant input from ecosystem goods. It is important to note that compared to the other three unit processes, cultivation is the most crucial unit process during the whole biodiesel life cycle, embodying 74% of the mass input. This implies that the downstream process is very critical in the whole palm oil biodiesel life cycle, and therefore sustainable management of the downstream process contributes a lot to the sustainability of palm oil biodiesel supply chain. Result from energy analysis (graph not shown here) indicates that fossil fuels from the lithosphere and solar energy in ecological services are the major energy contributors providing more than 10^4 MJ of energy per ton of POB. Unlike results from the conventional LCA where the role of solar energy is not counted, Eco-LCA result indicates that solar energy is the biggest contributor in terms of energy input. This indicates the large quantity of solar energy enters the economy via photosynthesis in the agricultural and forestry sectors.

4. Conclusions

This study has been able to demonstrate the static life cycle analysis part of the LCSA methodology through a novel approach that couples the ISO LCA and the Eco-LCA. This study has also provided insights on how ecosystem goods and services are associated with the value chain of palm oil biodiesel. Despite the fact that almost 100% of the energy inputs are renewable, it cannot be interpreted that the palm oil biodiesel is completely sustainable. The rates of consumption and regeneration are two key-factors which need to be considered in judging system sustainability; consumption rate that exceeds the ecosystem's ability for the regeneration will result in the deficit of ecological supply. This big picture is essential to understand the critical ecological issues in producing palm oil biodiesel, which is an important consideration in an integrated, system-perspective decision making process for formulating policies that favor sustainable development.

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