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Environmental Potential Impact on Biofuel Production from Thermal Cracking of Palm Shell Using Life Cycle Assessment

Rusdianasari[1], Leila Utarina[1*], Leila Kalsum[1], Daya Wulandari[1], Yohandri Bow[2]

[1] Department of Renewable Energy Engineering, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Bukit Besar Palembang, 30139, Indonesia

[2] Department of Energy Engineering, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Bukit Besar Palembang, 30139, Indonesia

* Corresponding author's email: leilautarina99@gmail.com

ABSTRACT

The aim of the study was to determine the environmental potential impact of the palm shell biofuel production process using life cycle assessment (LCA) through gate to gate approach. The environmental impact of each scenario was assessed using ISO 14040 (2006), which includes goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation. The simapro v.9 software with ecoinvent 3.5 database was utilized to assess the environmental effect. The impact analysis method used is Impact 2002+. Functional units were used to show environmental references in damage assessment and characterization, such as energy use and global warming potential. The results show that the environmental impact evaluation obtained through LCA for the entire biofuel production process stated that the thermal cracking stage resulted in the highest global warming impact, compared to other processes, which was 118.374 kg CO_2 eq. For the categories of human health, ecosystem quality, and climate change, each has a value of 0.0001 DALY; 15.708 PDF·m²·yr; and 335.233 kg CO_2 eq where this value is the total damage assessment of the entire biofuel production process. From the results of the analysis by utilizing the networking graph on the simapro application, it can be seen that the environmental hotspot of the thermal cracking process of biofuel production is due to the use of electricity from the State Electricity Company (PLN) and the release of chemical substances from the process. To improve the environmental performance of biofuel production process, additional development steps are required to increase biofuel yield, purification efficiency of biofuel to obtain pure liquid fuel, and the use of renewable energy sources to generate electricity. Additionally, more particular data would be required for a more precise LCA study result.

Keywords: biofuel; life cycle assessment; palm shell.

INTRODUCTION

Currently, Indonesia's energy needs are not matched by the availability of fossil energy (Wulandari et al., 2022; Yunsari et al., 2019). In response to rising energy demand, depletion of fossil-based resources, and environmental consequences of using non-renewable energy sources, the exploration of alternative renewable energy sources is essential to attaining green and sustainable development (Chan et al., 2018). Biomass energy has the potential to be utilized as a renewable energy source. Due to its availability, lignocellulosic biomass has been adopted as a raw material for biofuel production worldwide (Rattanaporn et al., 2017). Utilizing biomass energy as fuel is referred to as biofuel. Biofuels are liquid fuels derived from vegetable oils (Bow et al., 2020). The biomass waste from forests, plantations, industries, and households can be utilized to produce vegetable oil. Palm oil waste is one of the potential biomass types that can be utilized.

Indonesia is currently the world's largest producer of palm oil. Palm oil is generated in palm oil refineries by refining crude palm oil (CPO) (Sabarman et al., 2019). The production of palm oil results in the daily generation of waste; this includes solid waste in the form of empty fruit bunches (EFB), fibers, and palm shells, as well as liquid waste in the form of slurry oil. Shells from palm oil are one of the most significant by-products of palm oil processing, accounting for as much as 60 percent of total oil output. To this day, palm kernel shells have only been utilized as a fuel for boilers, which provides both heat and mechanical energy, or as a landfill material (Lau et al., 2019). This utilization has not maximized the components contained in palm shells. The advanced technology that is currently available may be used to process palm oil shells, which allows for optimal use as well as the creation of biofuels.

The application of conversion technology must be suited to the properties of the biomass. Variable proportions of hemicellulose, cellulose, and lignin are present in oil palm biomass waste. Because palm oil biomass waste consists of lignocellulosic materials with a high lignin content, it is incompatible with the biochemical process (Wang et al., 2020). The thermochemical conversion technique known as thermal cracking is the type of technology that can be utilized for the process of conversion. During the thermal cracking process, the raw materials that contain cellulose components of up to 81.41% and hemicellulose of up to 44.2% can be converted into biofuels, while lignin can be converted into charcoal at a rate of 40.33% (Xu et al., 2020). The production process of the biofuel from biomass waste including palm shell may have environmental consequences that require further study.

Life Cycle Assessment, also known as LCA, is a method that can forecast and analyze the impact that a product or process has on the environment, assuming that it is sustainable (Darojat, 2019). LCA is also defined as a method for evaluating the performance of a product system or technical process based on its effects on the environment over the course of its life cycle. This evaluation can be done at any time during the product's life cycle (Zhou et al., 2017). The LCA approach makes it feasible to examine the environmental impacts that emerge from all stages in the life cycle of a product, including the impacts that are frequently missed in the analyses carried out using traditional methods. This is one of the primary benefits of the LCA process. Some examples of the impact are the removal of waste, the transportation of materials, and the disposal of waste. The LCA is able to provide a more thorough perspective of the environmental impacts of a product or process that already exists (Meex et al., 2018). An in-depth LCA study that begins at the beginning of the process and continues until the product is used can serve as a foundation for decision-making on the technologies involved in biomass conversion. LCA follows a step-by-step and methodical process that is broken down into four stages which can be explained in Figure 1.

The adoption of LCA in Indonesia is still in its infancy, as seen by the comparative paucity of publications compared to other Southeast Asian nations (Wiloso, 2019). However, during the past five years, there has been a considerable growth, reflecting a growing interest in LCA, as was the case with a number of previous studies utilizing the same technique as thermal conversion when biomass is converted into biofuel (Dang et al., 2014; Guo et al., 2017), as well as LCA

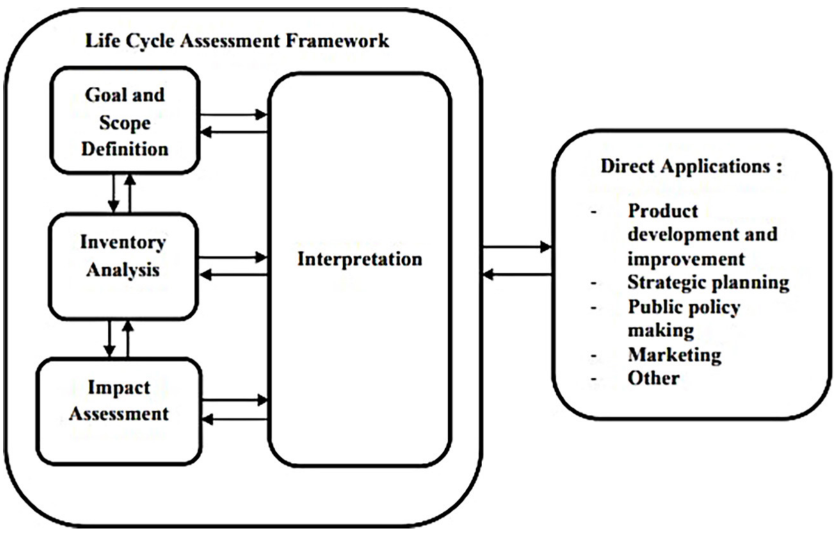

Figure 1. LCA Phases Framework (Fiksel, 2009)

perspective on biofuel production (Togarcheti et al., 2017; Chan et al., 2018). In addition, none of these publications investigated the environmental implications using a systematic LCA. The process of converting biomass waste may have the environmental effects that require further investigation. In addition, this study seeks to identify the difficulties and opportunities facing LCA research in Indonesia.

METHODOLOGY

LCA is utilized to identify, measure, analyze, and quantify the consumption of resources/raw materials, energy, chemicals, products, emissions/waste, and other production-related elements (Finkbeiner, 2013). On the basis of ISO 14044-2006, the LCA stages consist of (1) Determining goals and boundaries (goal and scope); (2) life cycle inventory (LCI) includes the input and output data on the production process of oil palm shell biofuel; (3) life cycle impact assessment (LCIA), an assessment of the impact to the environment using the Impact 2002+ method; (4) Interpretation, The phase of deriving findings based on the correlation between LCI and LCIA and determining environmental improvement recommendations.

This research was conducted in the chemical laboratory of Politeknik Negeri Sriwijaya, and the environmental impact assessment was completed utilizing the simapro v.9 software and ecoinvent 3.5 database. This database serves as a reference for the data hypothetically. Primary data in the program is derived directly from field study, while secondary data comes from appropriate sources.

RESULTS AND DISCUSSION

Goal and scope definition

The first step of an LCA study is establishing objectives and scopes. This study sought to determine the potential environmental effects of the biofuel generation process using oil palm shells. This LCA study approach is highly effective for enhancing process efficiency and providing accurate environmental load assignments to optimize environmental improvements, and it enables the modeling of multiple products using a single process (Wulandari et al., 2022). Meantime, the scope of the LCA analysis in this study is gate to gate, encompassing only the processing of palm shell to produce the product. The impact analysis method used is Impact 2002+ (Jolliet, 2013) with the impact analyzed in the form of (1) damage assessment; human health, ecosystem quality, climate change and resources and (2) characterization; Non-renewable energy, non-carcinogens, aquatic ecotoxicity, carcinogens, global warming, ionizing radiation, terrestrial ecotoxicity, terrestrial acid, aquatic acidification mineral extraction, respiratory inorganics, respiratory organics, aquatic eutrophication, ozone layer depletion, land occupation. System boundary defined by a dashed-line box for production from thermal cracking. Figure 2 shows the system boundary of this study.

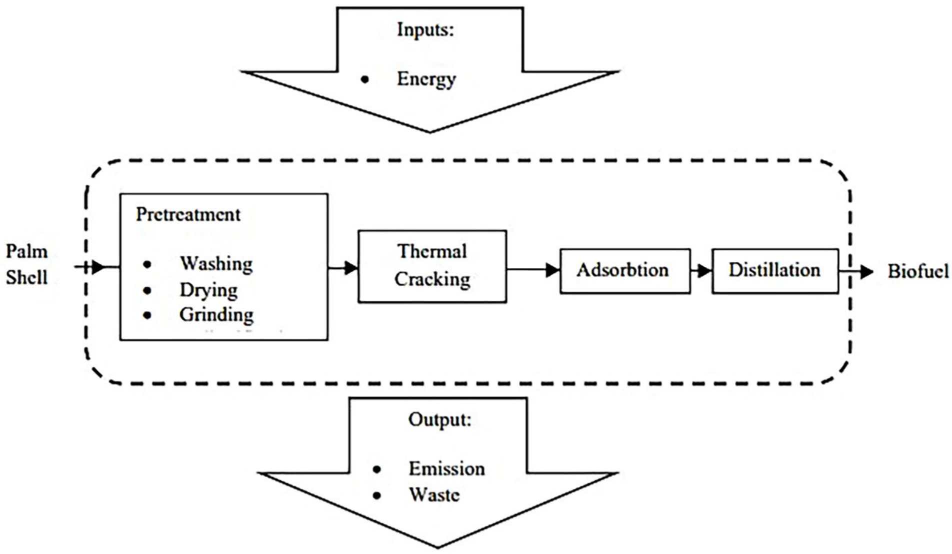

Figure 2. Boundary system of biofuel production process

Life cycle inventory

The second stage is LCI. The conceptual process and working condition of this study are founded on the authors' prior lab-scale experimental method and outcomes (Rusdianasari et al., 2022; Utarina et al., 2022). The input and output inventory stage of the palm shell biofuel production process or LCI is adjusted based on Table 1. Input data is in the form of materials / raw materials, energy, and chemicals. In turn, output data is in the form of production results, production by-products (waste) and emissions.

The biofuel production process with thermal cracking consists of pre-treatment, thermal cracking, adsorption, and distillation processes. This process produces a product, namely biofuel, and by-products in the form of gas and charcoal. The data used in this life cycle inventory is data taken under operating conditions with a temperature of 450°C because that temperature produces the most optimal biofuel product compared to other temperature conditions. Each process is interconnected with each other, because the product of each process affects the product results in the next process and forms a data flow called networking.

Life cycle impact assessment

The next stage was LCIA. At this stage, all input and output data obtained are entered and processed using SimaPro V.9 software. The method used to estimate the magnitude of the environmental impact on the biofuel production process from oil palm shells is Impact 2002+. The Impact 2002+ method has four main impacts in damage categories; human health, ecosystem quality, climate change and resources. Meanwhile for characterization, there are the following categories: Non-renewable energy, non-carcinogens, aquatic ecotoxicity, carcinogens, global warming, ionizing radiation, terrestrial ecotoxicity, terrestrial acid, aquatic acidification mineral extraction, respiratory inorganics, respiratory organics, aquatic eutrophication, ozone layer depletion, land occupation. The impact results processed using SimaPro V.9 software are presented in Table 2, Table 3, Figure 3, and Figure 4.

Interpretation

Damage assessment

Damage assessment is an analysis that utilized to measure the impact of the ensuing damage based on its characterization impact (Volta et al., 2021). This analysis is useful as a consideration in making decisions to improve the environmental performance. Table 2 shows the categories of damage by biofuel production activities. Below is an explanation of multiple units, including MJ primary, kg CO_2 eq, PDF·m^2·yr, and DALY

Table 1. LCI of biofuel production process

Category	Inventory data	Amount	Unit
Input			
Material	Fresh palm shell	18	kg
	Pretreated palm shell	15	kg
	Natural zeolite	2	kg
	Tap water	6E-03	m^3
	Aquadest	3E-03	m^3
Energy	Drying shed	18	kWh
	Grinder	18.5	kWh
	Oven (120 °C)	0.75	kWh
	Hotplate	1	kWh
	Heater in thermal cracking reactor (300–450 °C)	1200	kWh
	Pump	38	kWh
Solvent	HCl 10%	1.8E-02	m^3
Output			
Product	Biofuel	29.73	%
Emission	Gas	30.81	%
	Char	39.46	%

Table 2. Damage assessment of biofuel production process

Damage category	Unit	Total	Pretreatment	Thermal cracking	Adsorbtion	Distillation
Resources	MJ primary	6593.348	5.139578	2123.801	2134.29	2274.227
Climate change	kg CO_2 eq	335.233	0.51253	106.021	106.91	118.374
Ecosystem quality	PDF*m²*yr	15.708	0.007756	4.560	4.740	5.236
Human health	DALY	0.0001	1.65E-05	2.41E-05	2.46E-05	2.69E-05

Table 3. Characterization of biofuel production process

Impact category	Unit	Pretreatment	Thermal cracking	Adsorbtion	Distillation
Non-renewable energy	MJ primary	5.139	2123.358	2133.745	2273.554
Non-carcinogens	kg C_2H_3Cl eq	4.881	3.276	3.306	3.349
Aquatic ecotoxicity	kg TEG water	3.724	2021.062	2956.419	3138.572
Carcinogens	kg C_2H_3Cl eq	0.966	0.853	0.861	0.876
Global warming	kg CO_2 eq	0.512	118.374	56.911	106.020
Ionizing radiation	Bq C-14 eq	0.306	77.96239	81.381	241.522
Terrestrial ecotoxicity	kg TEG soil	0.280	479.508	494.304	543.092
Terrestrial acid/nutri	kg SO_2 eq	0.005	0.516	0.526	0.602
Aquatic acidification	kg SO_2 eq	0.001	0.089	0.092	0.113
Mineral extraction	MJ surplus	0.0001	0.443	0.551	0.6728701
Respiratory inorganics	kg $PM_{2.5}$ eq	0.0001	0.017	0.0184	0.021
Respiratory organics	kg C_2H_4 eq	4.73E-05	0.011	0.011	0.012
Aquatic eutrophication	kg PO_4 P-lim	7.46E-06	0.001	0.001	0.002
Ozone layer depletion	kg CFC-11 eq	1.36E-08	5.99E-06	6.09E-06	6.68E-06
Land occupation	m²org.arable	8.77E-09	0.117	0.123	0.143

that can be used to calculate the amount of damage caused by an event (Volta et al., 2021).

1. DALY is the amount of years a person loses due to health issues, disability, or early death. One DALY equals one year of healthy life lost. There is 0.0001 of the total DALY in human health based on damage assessment of biofuel production process. Each process only has a small difference in the range of DALY.
2. PDF·m²·yr is the proportion of species/ecosystem that could be lost per m² per year. This unit is used to measure an ecosystem's influence. One PDF·m²·yr is equivalent to 1 m² of damage to species or ecosystems on the Earth's surface over the course of 1 year. Pre-treatment has the smallest value compared to other processes. This is because the pre-treatment waste can still be recycled in the existing ecosystem.
3. MJ Primary is the amount of energy needed to extract a natural resource. The total MJ Primary of the whole production process is 6593.348.
4. Kg CO_2 eq is the unit of measure for the category of impact characteristics of global warming, and the consequence is global climate change. According to the analysis in Figure 4, the thermal cracking, adsorption, and distillation procedures all have the same global warming impact distribution.

Characterization analysis

Characterization is quantity evaluation of the chemicals that contribute to the impact category in biofuel production based on the characterization characteristics of such substances as shown in Table 3. In the other words, the substances listed in characterization are described the consisting material inside damage assessment. In this characterization analysis, it is known that each activity in the biofuel production process has the same potential value for each impact in different units. There are 15 impact categories that have been successfully analyzed in the application. For a clearer comparison, a graphical image can be seen in Figure 3. The thermal cracking process is the process with the largest impact category, then followed

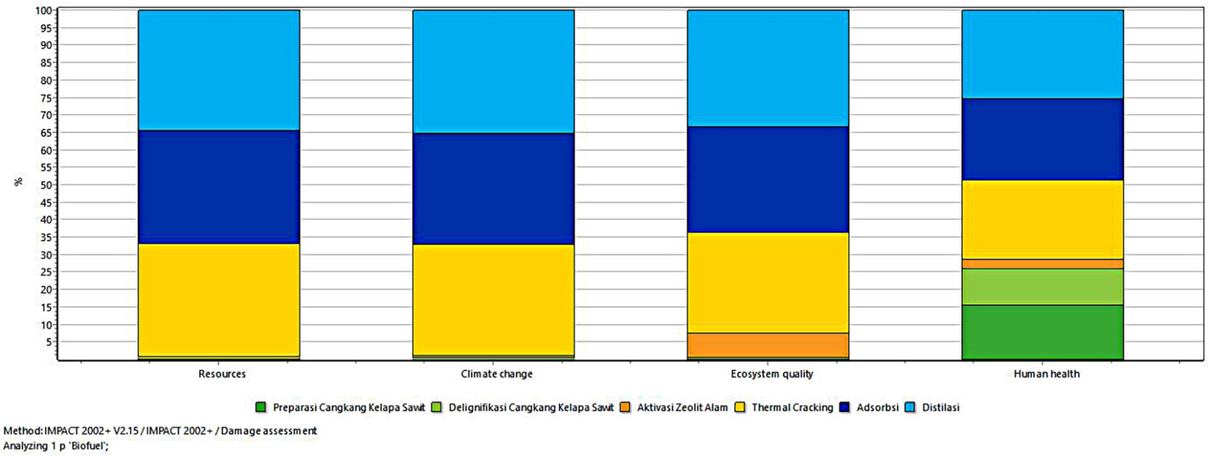

Figure 3. Damage assessment's graph

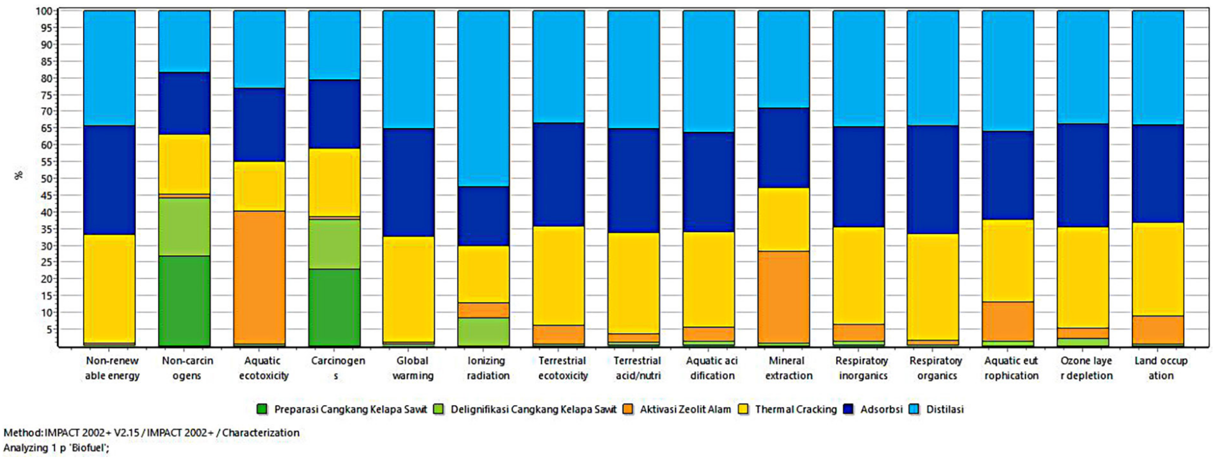

Figure 4. Characterization's graph

by the distillation process. Thermal cracking has an impact on global warming of 118.37437 kg CO_2 eq, where this value is the largest value among other processes. Meanwhile, the process that has the lowest impact on global warming is the raw material preparation process, which is 0.5125298 kg CO_2 eq.

CONCLUSIONS

In this study, the LCA of palm shell biofuel production process was presented. On a gate to gate basis, the environmental performance of this process in terms of numerous environmental consequences was calculated. The results show that the environmental impact evaluation obtained through LCA according to ISO 14044 for the entire biofuel production process stated that the thermal cracking stage resulted in the highest global warming impact compared to other processes, which was 118.374 kg CO_2 eq. For the categories of human health, ecosystem quality, and climate change each has a value of 0.0001 DALY; 15.708 PDF·m^2·yr; and 335.233 kg CO_2 eq where this value is the total damage assessment of the entire biofuel production process. From the results of the analysis by utilizing the networking graph on the simapro application, it can be seen that the environmental hotspot of the thermal cracking process of biofuel production is due to the use of electricity from the State Electricity Company (PLN) and the release of chemical substances from the process. To improve the environmental performance of biofuel production process, additional development steps are required to increase biofuel yield, purification efficiency of biofuel to obtain pure liquid fuel, and the use of renewable energy sources to generate electricity. Additionally, more particular data would be required for a more precise LCA study result.

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