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Life Cycle Assessment of Production Bio-oil from Thermal Cracking Empty Fruit Bunch (EFB)

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A B S T R A C T

Empty fruit bunch (EFB) is one of the abundant biomass waste from oil palm and it is an issue that it can be used as renewable energy in the form of Bio-oil. Bio-oil is produced by a thermal cracking process. This research aims to identify the potential environmental impact of Bio-oil production from EFB as fuel. Life Cycle Assessment (LCA) with gate to gate approach is used in data processing applications for networks in Simapro V.9 and the database used is similar to the characteristics of the eco invent database. Functional units are used to show environmental references in impact categories, such as energy used and global warming potency. The results show that the stage of the bio-oil production cycle in the pretreatment process has a greater global warming impact than the others, amounting to 131.10013 kg CO_2 eq. The results of the analysis using the networking graph on the Simapri, show that the environmental hotspot of the thermal cracking process for Bio-oil production is caused by the use of electricity from the State Electricity Company (PLN) and the release of chemical substances from the process. From the results of the LCA, environmental performance improvement or continuous improvement can be done is by managing energy use and installing equipment.

1. INTRODUCTION

1.1. Research Background

The number of production of oil palm plantations in the world, especially in Indonesia, continues to increase. In 2018, the area of oil palm plantations was 14.33 million hectares with a production value of 42.9 million tons. In 2019, the area of oil palm plantations increased by 1.88 percent to 14.60 million hectares with an increase in CPO production of 12.92 percent to 48.42 million tons. The increase in area and production in 2019 compared to the previous year was due to an increase in the administrative scope of palm oil companies [1]. In addition to increasing production and market projections for the palm oil industry, the other hand, palm oil mills can cause problems, such as an increase in the volume of their waste. Various types of solid waste are generated from palm oil processing. Seed shells, fruit fibers, and EFB are the main solid wastes generated during the milling process while leaves and stems are obtained from plantations in the process of harvesting, pruning, and felling. [2]. Biomass waste in the form of seed shells, fruit fiber, and empty fruit bunches in palm oil mills is generally used directly as boiler fuel. Although burning waste as fuel can reduce diesel consumption, this action is not environmentally friendly because it produces emissions in the form of smoke and dust from incomplete combustion. [1]. This abundance of biomass waste needs to be utilized because it can contribute to providing great potential for the provision of renewable and sustainable energy sources [3]. The use of conversion technology needs to be applied according to the characteristics of the biomass. Oil palm biomass waste contains hemicellulose, cellulose, and lignin with varying compositions. The biochemical process is not suitable for palm oil biomass waste because of its characteristics as a lignocellulosic material with a fairly high lignin content so it is more difficult to degrade. [4],[5]. Conversion technology that can be applied is thermochemical, namely pyrolysis. The pyrolysis process can convert raw materials containing cellulose components as much as 81.41% and 44.2% hemicellulose into bio-oil, while 40.33% lignin will become charcoal [6]. The process of converting biomass waste can cause environmental impacts that need to be studied. Life Cycle Assessment (LCA) is a method used to predict and analyze sustainable environmental impacts on the life cycle of products and processes. LCA is defined as an objective process for evaluating the environmental loads associated with a product, process, or activity by identifying and measuring the use and release of energy and materials into the environment and evaluating and implementing opportunities

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to effect environmental improvements [7] LCA is used to assess the energy balance and Global Warming Potential (GWP) of EFB Bio-oil production [8]. LCA is also used to evaluate environmental impacts based on the life cycle of electricity production using EFB [9]. An in-depth study of LCA starting from the beginning of the process to its utilization can be used as a basic guideline for decision-making concerning biomass conversion technology [10].

1.2. Literature Review

EFB is waste from a palm oil mill which was previously fresh fruit bunches (FFB) that have gone through a sterilizer and tippler process. The amount of EFB produced per tonne of FFB processed reaches about 23%, but it has not been widely used and its management is still limited to only burning and some of it is left as plant mulch. Empty bunches contain cellulose 41.3% - 46.5% ($C_6H_{10}O_5$)n, hemicellulose 25.3% - 32.5% and lignin 27.6% - 32.5% [4],[11]. With this content, EFB has the potential as an energy source in the form of Bio-oil [4]. The process of making Bio-oil with EFB as raw material has been carried out by several previous studies. In general, the right process is needed to produce this Bio-oil. Thermal cracking is one of the ways to make Bio-oil whereas pyrolysis is a drying process by incomplete combustion of materials containing carbon at high temperatures. [12]. As for several previous studies that have been carried out with the same process as pyrolysis where EFB becomes Bio-oil [13],[14], In addition, research on the purification of Bio-oil into biofuel on the performance of the pyrolysis reactor through an active zeolite filtration process shows that natural zeolite can be used as an adsorbent for bio-oil to become biofuel [15],[16]. Utilizing biomass as an energy source will certainly reduce its impact on the environment, but this needs to be reviewed using LCA [17]. Based on this research, it can be concluded that the results obtained from the LCA can be used as a source of information to minimize pollution and energy efficiency to support the company's sustainability and meet the reduction of greenhouse gas emissions that has been set by the government.

1.3. Research Objective

This study aims to evaluate the environmental impact of the Bio-oil production process from the preparation of EFB, to the production of Bio-oil.

2. MATERIALS AND METHODS

In this study, the raw material in the form of EFB produces Bio-oil with a thermal cracking process and by-products in the form of charcoal and syngas to offset the need for fossil fuels as energy generators, but the Bio-oil production process needs to be carried out by LCA. LCA method is used to estimate and environmental impacts are carried out based on the principles and framework in ISO 14010: 2006 consisting of (1) The Goal and Scope Definition, (2) Life cycle Inventory (LCI), (3) Life cycle impact assessment (LCIA), and (4) Interpretation.

The assessment uses the SIimapro v.9 software with the Ecoinvent 3.5 databases. This database is used as a reference approach for the data which will be assumed to be production data that has been processed as primary data and supporting data are used from several closest and most relevant references.

2.1. Goal and Scope Definition

The scope of this report is gate to gate where only the scope of this report is gate to gate where only the processing of raw materials in the form of EFB produces Bio-oil products. SIMAPRO models the different stages of the life cycle of Bio-oil production which consist of preparation, pretreatment, and thermal cracking. This LCA analysis approach is very useful to improve process efficiency and provide realistic assignment of environmental loads to optimize environmental improvements and this approach provides an opportunity for one process to be used to model other products.

2.2. LCA

This research includes LCI and LCIA of Bio-oil. The LCI measures all emissions associated with all preparation, pretreatment, and thermal cracking research activities. The LCA model was developed using the Simapro environmental modeling application [18],[19]. Green House Effect (GHE) impacts are calculated using a 100-year global warming potential [20].

2.3. Preparation

Bio-oil production with the thermal cracking process will be related between one process unit and the others. EFBs are dried for about two days to remove any unattached moisture. The dried EFB were then ground using a grinding machine and sieved to obtain a particle size of about 1-2 mm. After that, the sample was dried in the oven for 24 hours at 40°C.

Table 1. EFB preparation Inventory Data

No	Input	Total	Unit
Material			
1	EFB	19.2	kg
2	Water	2.96E-03	m3
Energy			
3	Drying Shed	18	kWh
4	Grinding	18.5	kWh
Product			
5	Fine Production	18	kg
6	Ash, etc	2	kg

Fig 1. Preparation EFB
(A) EFB material, (B) Sun-dried EFB (C) EFB Drying in the Oven, and (D) EFB size-reduction

2.4. Pre-treatment

From the product preparation process from EFB in the form of fine production, 10% acid delignification pretreatment was carried out to increase the calorific value. The 18 kg sample was filled with HCl solution with a concentration of 10%. The sample was heated on a 121°C hotplate for 30 minutes. The sample was filtered and washed with water until the pH was neutral. The resulting residue was dried in an oven with a temperature capacity of 105°C for 1 hour.

Table 2. EFB Pretreatment Inventory

No	Input	Total	Unit
Material			
1	EFB	11.8	kg
2	HCL 10%	1.8E-02	m3
3	Water	2.96E-03	m3
Energy			
4	Electric Hotplate (121 ºC)	1	kWh
5	Electric Oven	0.75	kWh
Product			
6	EFB Delignification using HCL 10%	16	Kg
7	Landfill	2	Kg

2.5. *Thermal Cracking Process*

The thermal cracking process uses raw materials with 10% delignification. EFB as much as 2-3 kg is inserted into a stainless steel tubular reactor with a length of 360mm and an inner diameter of 214 mm. The reactor is heated externally with the help of a heater with the temperature-controlled by a type K thermocouple placed inside the reactor. The temperature used in the pyrolysis process is 300°C, 350°C, 400°C, and 450°C {Formatting Citation}. The flow for the conversion of steam to liquid uses a condenser whose flow uses a pump. A more detailed description of the prepared pyrolysis is shown in Figure 2.

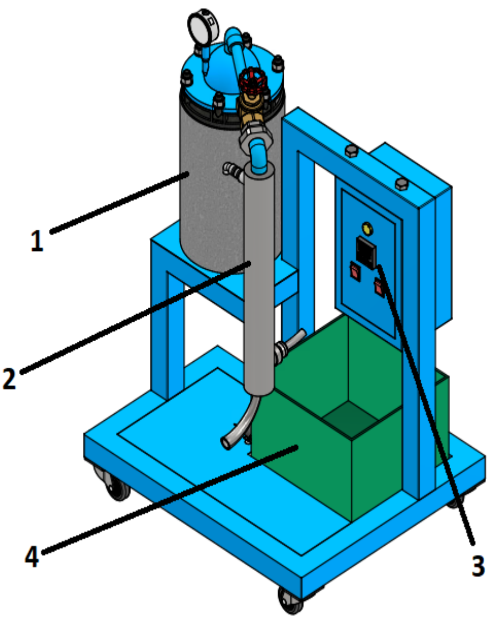

Fig 2. Thermal Cracking Reactor used in research (1) reactor, (2) condenser, (3) panel control, (4) water tank

Table 3. EFB Thermal Cracking Inventory

No	Input	Total				Unit
		300 ° C	350 ° C	400 ° C	450 ° C	
Material						
1	EFB Delignification of 10% HCL	3	3	3	3	kg
Energy						
2	Heater	1200	1200	1200	1200	kWh
3	Water Pump	38	38	38	38	kWh
Product						
4	Bio-oil	16.25	20.54	25.87	29.26	%
5	Gas	18.99	21.14	28.86	31.03	%
6	Coal Mass	64.76	58.32	45.27	39.71	%

3. RESULT AND DISCUSSION

3.1. *Life Cycle Investment (LCI)*

Bio-oil production process with thermal cracking consists of preparation, pretreatment, and thermal cracking processes. This process produces 3 products, namely Bio-oil, gas, and charcoal. The utilization of EFB with the highest impact on thermal cracking comes from power plants. Details for each impact category are discussed in the sections below. The data used in this LCI is data taken at operating conditions with a temperature of 450ºC because that temperature produces the most optimal Bio-oil product compared to the others.

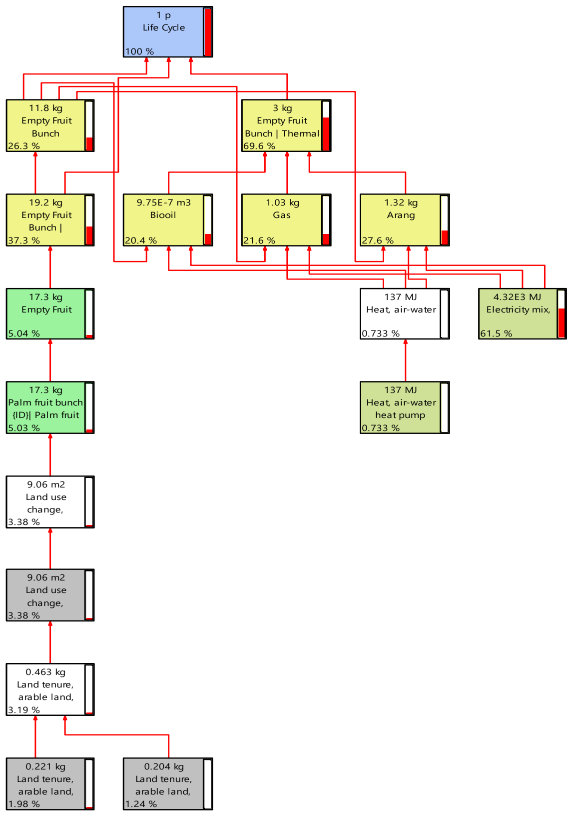

Fig 3. Bio-oil Production Process Network

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3.2. LCIA

After the networking is done, the process that contributes the most to the environmental impact will be known. Data for the network is processed in Simapro V.9 for the database used is similar to the characteristics of the eco invent database. Impact analysis in this study uses the Impact 2002+ method [22].

3.3. Characterization Analysis

In this characterization analysis, it is known that each activity in the Bio-oil production process has the same potential value for each impact in percent units. This indicates that there is a need for further analysis to find out which activities and impacts have the greatest emissions. The following is a character analysis of the production of Bio-oil from EFB through the thermal cracking process in Table 3 which has 15 impact categories, but this figure cannot be ascertained as the largest, considering that the units between impacts are not the same. For example, the impact of Global Warming has units of kg CO_2 eq, which is an estimate of equivalent carbon dioxide emissions where the thermal cracking process has the greatest value of 131.10013 kg CO_2 eq compared to the preparation and pretreatment processes.

Table 3. Result of characterization value of Bio-oil Production process from EFB

Impact category	Unit	Total	EFB | Preparation	EFB Delignification of 10% HCl | Pretreatment	EFB | Thermal Cracking EFB
Carcinogens	kg C2H3Cl eq	0.51214183	0.11862611	0.19247853	0.20103719
Non-carcinogens	kg C2H3Cl eq	2.5998486	0.65929613	1.0691124	0.87144007
Respiratory inorganics	kg PM2.5 eq	0.057600272	0.00740925	0.012289046	0.037901976
Ionizing radiation	Bq C-14 eq	25140.87	1.7862405	3.0713028	25136.013
Ozone layer depletion	kg CFC-11 eq	0.000228426	4.42E-08	7.31E-08	0.000228309
Respiratory organics	kg C2H4 eq	0.022088291	0.003485576	0.007727939	0.010874776
Aquatic ecotoxicity	kg TEG water	9903263.6	3031457.6	4913277	1958529.1
Terrestrial ecotoxicity	kg TEG soil	375.59696	80.603684	131.05579	163.93749
Terrestrial acid/nutri	kg SO2 eq	1.4310091	0.12390916	0.20687997	1.10022
Land occupation	m2org.arable	10.991403	3.3602596	5.4461863	2.1849571
Aquatic acidification	kg SO2 eq	0.30638414	0.016688522	0.028894097	0.26080152
Aquatic eutrophication	kg PO4 P-lim	0.06872797	0.02070657	0.033565682	0.014455719
Global warming	kg CO2 eq	151.24092	6.456976	13.683809	131.10013
Non-renewable energy	MJ primary	8268.844	6.2770411	17.681077	8244.8859
Mineral extraction	MJ surplus	0.11713705	0.009628049	0.015788999	0.091720005

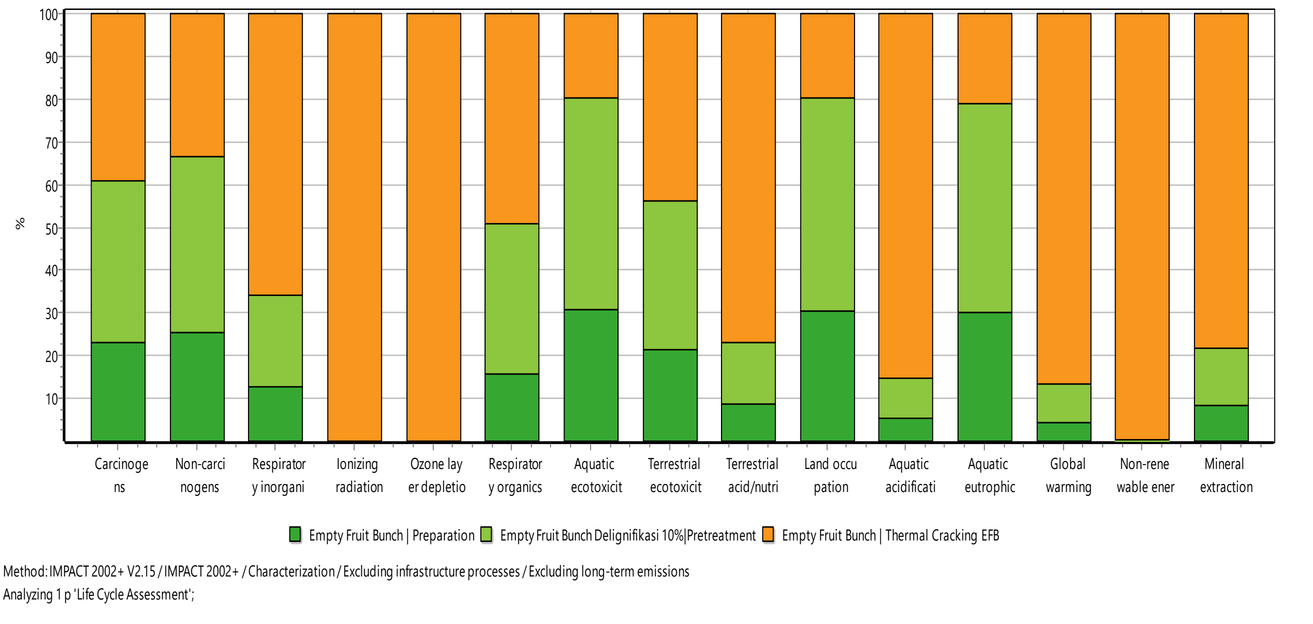

Fig. 4. Characterization Chart of Bio-oil Production

3.4. Weighting and Single Score Analysis

The bio-oil production process enters a weighting and single score analysis which results in a major impact on Human Health. This result is different from the previous analysis because the weighting and single score analysis have the same unit (mPt) with the same unit value, it can be concluded that human health has the greatest impact on the Bio-oil production process in Table 4, namely thermal cracking due to This process produces bio-oil, gas, and charcoal which have an impact on the environment.

Table 4. The results of the Weighting and Single Score category for the Bio-oil Production process from EFB

Damage category	Unit	Total	Empty Fruit Bunch | Preparation	Empty Fruit Bunch Delignification 10%|Pretreatment	Empty Fruit Bunch | Thermal Cracking EFB
Total	mPt	114.87534	13.165449	21.741867	79.968024
Human health	mPt	7.6986341	1.039523	1.7134277	4.9456835
Ecosystem quality	mPt	37.491609	11.432406	18.52993	7.5292737
Climate change	mPt	15.275333	0.65215458	1.3820647	13.241114

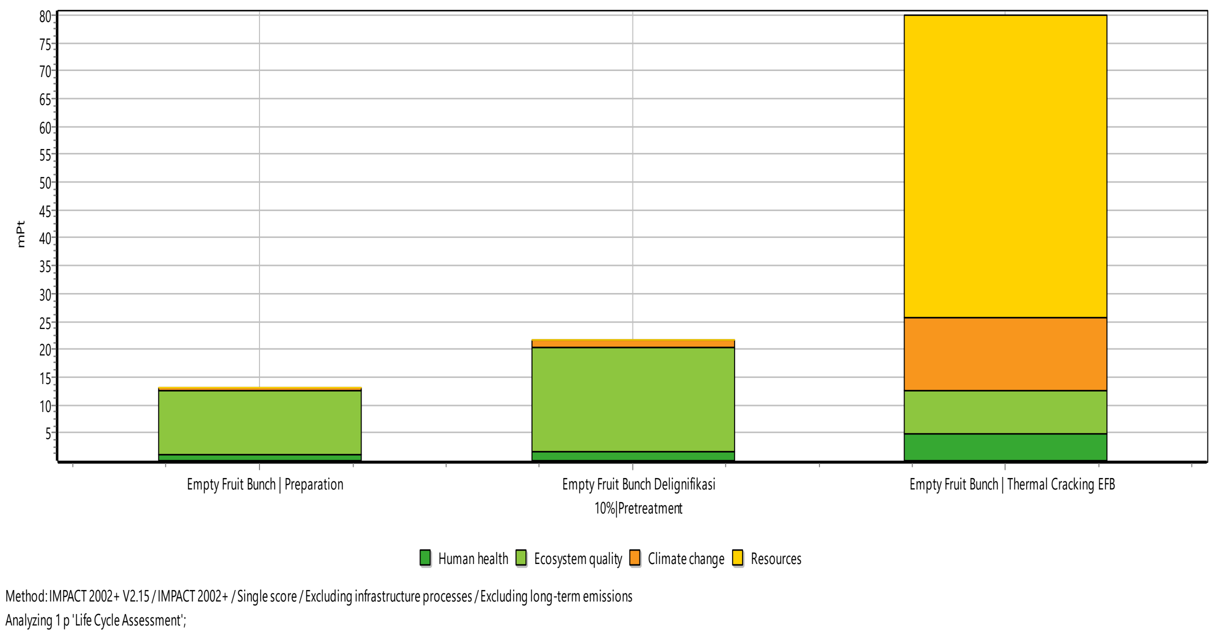

Fig. 5. Single Score Chart of Bio-oil Production

4. CONCLUSION

LCA is one way that can be used to analyze environmental performance in the Bio-oil production process. The results of the study showed that the production of Bio-oil from empty oil palm fruit bunches through the thermal cracking process using Simapro with Impact 2002+ method had the greatest impact on the environment, namely 131.10013 kg CO_2 eq compared to the preparation and pre-treatment processes. In the thermal cracking process, the environmental hotspot is the use of electricity from PLN and chemicals that come out of the process. From the results of the LCA, environmental performance improvement or continuous improvement can be done is by managing energy use and installing equipment

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