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Sustainable Biochar Production from Palm Kernel Shell Through Slow Pyrolysis: A Life Cycle Assessment of its Application as an Eco-Friendly Fertilizer

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Abstract. Palm Kernell Shell (PKS), a form of biomass waste can be transformed into higher-value products. In this study, PKS underwent pyrolysis process at various temperatures using a macro-thermogravimetry fixed-bed reactor. The research focuses on biochar production through slow pyrolysis and assesses the life cycle impact of biochar as a substitute for commercial fertilizer. The aim is to assess the effect of temperature variation on biochar properties and compare greenhouse gas (GHG) emissions between biochar-based and conventional fertilizers. The OpenLCA software was employed to conduct the life cycle assessment (LCA). The optimal temperature for biochar production through a slow pyrolysis process was identified as 450°C, yielding a carbon-to-nitrogen (C/N) ratio of 19.4. The study also investigated GHG emissions throughout the PKS lifecycle, involving oil palm cultivation, crude palm oil (CPO) milling, and biochar production through slow pyrolysis (cradle-to-gate). Substituting commercial NPK fertilizers with biochar in oil palm cultivation demonstrated significant reduction in GHG-related impacts, including global warming potential, acidification, eutrophication, and ecotoxicity by 3.6%, 20.7%, 10.7%, and 2.7% respectively.

1. Introduction

Climate change has become one of the major global issues faced by society nowadays. The Greenhouse gases (GHGs) effect becomes the main driver for climate change. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases are among the contributors to GHG emissions. These gases act like the glass in a greenhouse, trapping the heat from the sun, blocking it from escaping back into the cosmos, thus, raising the temperature of the earth, resulting in global warming.

Follett et al. (1993) mentioned that soil absorption can be one of the ways to help climate change mitigation by storing CO_2 as C (Carbon) in soil [1]. However, currently, the absorption capacity of soil as a GHG absorber demonstrates a declining trend due to the impact of land usage for agricultural and cultivation purposes, causing an increase in GHG emissions by 20% [2]. Moreover, the consumption of commercial/mineral fertilizers in the agricultural sector worsens the soil condition and contributes more to increasing GHG emissions, making the Agriculture, Forestry, and Land Use sectors become the second most producer of GHG emissions (accounting for 18.4% of GHG emissions) after the energy sector [3]. The commercial/mineral fertilizers consumption can produce emissions equivalent to 560 kg CO_2 eq kg^{-1} mineral fertilizer [4]. Therefore, the consumption of commercial/mineral fertilizers must be reduced in order to minimize the environmental impact.

Biochar can be one alternative solution to substitute commercial fertilizers. Biochar is a lightweight black-residue, carbon-rich material commonly produced from biomass thermochemical conversion and carbonization in anoxic high-temperature environments, respectively. It is formed due to the decomposition process of the lignocellulosic components (hemicellulose, cellulose, and lignin) in biomass. It has been proposed as a potential solution to energy security by substituting coal-based briquettes which tend to be expensive, and their availability is dwindling. Furthermore, biochar is preferable nowadays to replace commercial/mineral fertilizers due to its ability to maintain soil fertility longer and as a soil amendment. Soil amendment is crucial to be carried out because it assists plant productivity and encourages water and air quality, hence, the quality of human life and environment is increasing simultaneously [5]. One of the methods to achieve soil amendment for a long period is to utilize a resistant-to-decompose material, such as Biochar.

The application of biochar plays a crucial role in the agricultural soil layer as an alternative fertilizer, including soil structure improvement, soil organic carbon enrichment, soil pH enhancement, and prevention from erosion by resisting the water and soil, resulting in the rising of crop production indirectly [5]. Chan et al. (2008) studied that the using poultry litter biochar can be a contributor to soil amendment, as it increases Soil organic carbon (C-organic), soil pH, soil structure, soil CEC (cation exchange capacity), and groundwater storage capacity [6]. Referring to the release of emissions, the production and the application of biochar fertilizers not only emit less zero carbon dioxide emissions but also reduce CO_2 levels compared to the commercial/mineral fertilizers due to their capability to absorb the carbon from the active cycle and stash it to the inactive cycle. Moreover, its production employs biomass as raw material and the burning with absence of oxygen, so it doesn't generate any carbon dioxide as regular, oxygen-fueled fire does [7].

Palm oil biomass residue could be potentially used as a raw material for Biochar production. According to the Ministry of Agriculture-Directorate General of Plantations (2018), the development of palm oil area for agriculture in Indonesia has reached 10.31%/year between 1970 and 2017. The palm oil industry not only produces beneficial main products but also valuable biomass residues. The main product produced by the palm oil industry is crude palm oil (CPO) which is further refined and used for cooking oil, cosmetics, body and hair care, cleaning products, and biofuel. In addition, the biomass residues from palm oil industry such as Oil Palm Trunk (OPT), Oil Palm Frond (OPF), Empty Fruit Bunch (EFB), Palm Kernel Shell (PKS), and Mesocarp Fiber (MF) have high potential as a material for construction, furniture making, bio-composite, animal feed, bio-oil, compost, bio-absorbent, heat generation fuel, and biopolymer. Apart from that, among Empty Fruit Bunch (EFB), Palm Kernel Shell (PKS), and Mesocarp Fiber (MF), Palm Kernel Shell (PKS) turns out to be an excellent alternative material for biochar fertilizer due to its physical structure and biopolymer content in the biomass.

Biochar production undergoes a complex chemical reaction process, covering decomposition, depolymerization and condensation processes in oxygen-limited high-temperature conditions. Slow pyrolysis could be one of the carbonization methods to obtain biochar. It implies the process of biomass decomposition from long-chain hydrocarbon compounds into simpler molecules [8]. Generally, the pyrolysis method produces three products, such as gas (organic vapor), pyrolysis oil (liquid smoke), and char. Char/Biochar is formed due to the presence of lignin content in biomass that has not been degraded well at high temperatures [9].

In this study, biochar was obtained from Palm Kernel Shell (PKS) as residues from the Palm oil industry via slow pyrolysis. The using of biochar fertilizer in the agriculture sector, starting from the planting the palm oil tree to produce raw material for biochar, biochar carbonization through slow pyrolysis method (gate to gate), to the implementation of biochar as fertilizer, imply an inevitable energy consumption and GHG emissions [10]. Hence, the environmental safety of the production and application of Biochar fertilizer will be analyzed using a Life Cycle Assessment (LCA) approach to evaluate energy consumption and raw materials, emissions emitted into the environment, and other wastes related to the life cycle of a product or system [11]. However, it is believed that using biochar as a substitute or commercial fertilizer mixture helps to reduce GHG emissions while improving soil function as an absorber to capture emissions emitted in the area around the biochar industry [7].

LCA analysis can be carried out using OpenLCA software for easier applications to characterize the classification of the impact and analyze the ratio of the total impacts from each classification from the emissions produced. This research aims to elaborate on the production of biochar from Palm Oil Kernel Shell (PKS) via slow pyrolysis as a carbonization process and analyze the Life Cycle of biochar production and application using OpenLCA software.

2 Methods

The research consists of several stages, including the system boundaries, observation and experiment, and analysis. In the literature study stage, a literature study about the LCA approach, biochar as fertilizer, and the conversion process of palm oil biomass residue to biochar via slow pyrolysis, was studied. The LCA approach was conducted in the last stage.

2.1 Biochar Production from Palm Kernell Shell

Pretreatment of the raw material of Palm Kernell Shell (PKS) through a slow pyrolysis process was undergone to produce biochar fertilizer. Initially, the raw materials of the PKS were washed from impurities and dried under the sun's light radiation for 1 to 2 days followed by chopping into pieces approximately ± 2 mm in diameter. A modified version of the previously used reactor was employed in this study to facilitate the production of solid biochar [12]. Slow pyrolysis with a heating rate of 5ºC min^{-1} process was carried out in the reactor at various temperatures varying from 300ºC to 600ºC. High-purity N2 gas was used with a flow rate of 115 ml/min. The process used approximately 500 grams of PKS with a holding time of 30 minutes after reaching the final temperature. **Fig. 1** illustrates the macro-thermogravimetry fixed bed reactor, equipped with several thermocouples placed internally to monitor the temperature. Proximate analysis of the feedstock and products was performed using a Shimadzu TGA-3000 thermogravimetric analyzer to measure moisture (ASTM D-2173), volatile matter (ASTM D-3175), ash content (ASTM D-3174), and fixed carbon (ASTM D-3172, by difference). Ultimate analysis of carbon, hydrogen, oxygen, and nitrogen content was conducted using CHN Analyzer 628 Leco Series Elemental Determinators following ASTMD-5373 standard procedure. The biochar product was further characterized for its functional groups, morphology, and elemental composition using Fourier-transform infrared spectroscopy (FTIR) and scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS), respectively.

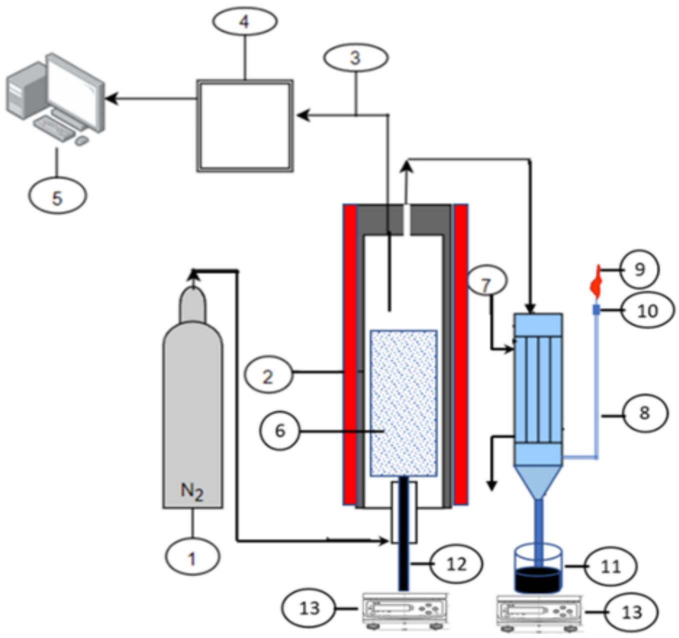

Fig. 1. Semi-batch fixed bed pyrolyzer schematic: (1) Nitrogen gas cylinder for reactor purge and seal; (2) Electric heater with a temperature controller; (3) Thermocouples; (4) Data logger; (5) Computer; (6) Feed cage; (7) Condenser; (8) Gas product pipe; (9) Pyrolysis gas flame; (10) Gas sampling tap, (11) Liquid product collector; (12) Cage support rod; (13) Digital scale [12,13].

2.2 Life Cycle Analysis

2.2.1 System boundary

Research on the impact of emissions issued during the biochar production process from PKS was carried out by LCA analysis. LCA analysis is performed by determining the goal and scope of the research, which is Greenhouse Gas (GHG) emissions as the potential factor for global warming. The scope of the research starts from the plantation of the Palm Oil tree stage, utilization of PKS as a waste of palm tree, into the production of biochar from Palm Oil Kernel Shell (PKS) is classified as cradle to gate scope and those stages are considered in the system boundary. Limiting the boundary system for the research is beneficial to determine the purpose and scope of the research. In this study, observation only focuses on greenhouse gas (GHG) emissions that have an environmental impact. The scope of this LCA analysis can be seen in the **Fig. 2.**

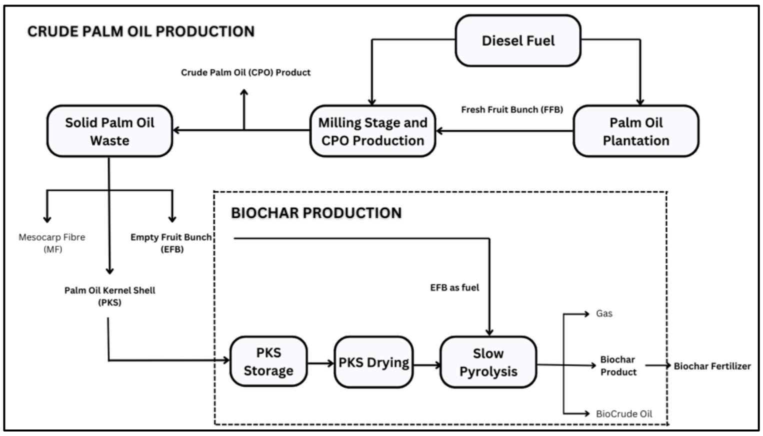

Fig. 2. The scope of LCA for biochar production and application

In this study, the Life Cycle Assessment (LCA) approach is divided into two primary components: Crude Palm Oil (CPO) production and biochar production. The emission calculation for CPO production focuses on three key stages including the cultivation of oil palm trees, the milling process, and the production of CPO. On the other hand, the emission analysis for biochar production is concentrated on the slow pyrolysis phase.

2.2.2 Investigated System, Model Assumptions, and Data Sources

The collection of secondary data was carried out by accumulating some data from previous research on Palm Oil Plantations, the milling process, and the pyrolysis process. Greenhouse gas emission factors from several components were obtained from the Emission Factor Database (EFDB) software and the JEC E3 Database. The impact analysis was analyzed by OpenLCA software using the BEES (Building for Environmental and Economic Sustainability) impact assessment method.

The scope for the Crude Palm Oil (CPO) production series includes the plantation stage, milling stage and CPO production stage as shown in **Fig. 3**. Palm Oil plantations are conducted by providing fertilizer regularly. The Palm Oil tree can be harvested every year for 2-3 years after the plantation stage until its optimum harvest age at 25 years. The fresh palm fruit bunches will be separated into fresh palm fruit and its biomass residues at the milling stage to produce Crude Palm Oil (CPO). The biomass residues from Palm Oil include Empty Fruit Bunch (EFB), Palm Oil Kernel Shell (PKS), and Mesocarp Fiber (MF). The Palm Oil Kernel Shell (PKS) simultaneously is delivered to the biochar production area with the following pretreatment steps involving washing, drying, and cutting the raw material. Lastly, the raw material is fed to the reactor to construct biochar products as fertilizer. The Empty Fruit Bunch (EFB) is used as fuel in the slow pyrolysis reactor.

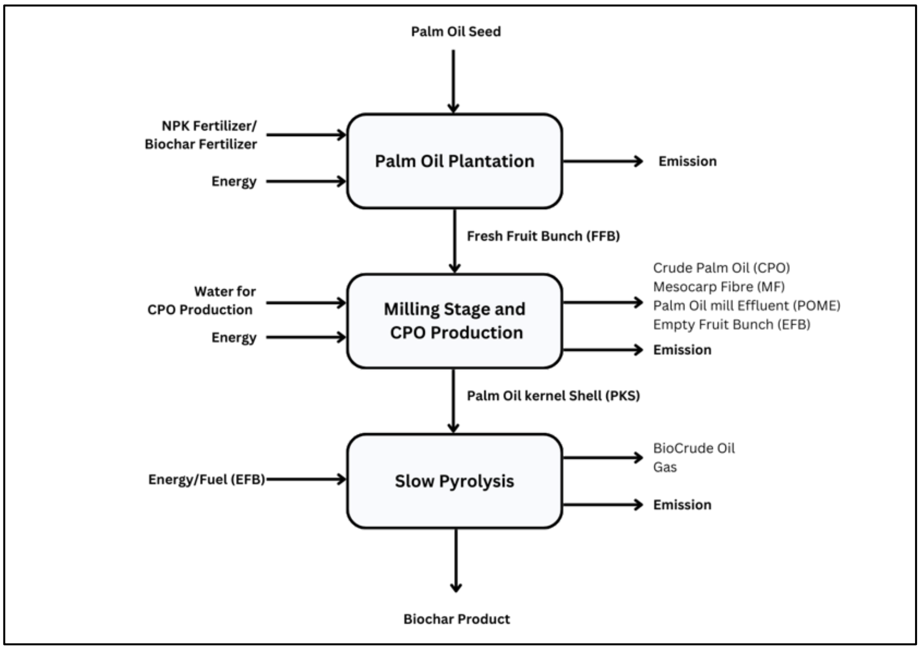

Fig. 3. Diagram flow of LCA approach for the production and application of biochar

The following stage involves conducting an inventory (LCI) by dividing it into five different scenarios. The scenario is differentiated by reducing the consumption of commercial fertilizers (NPKs) and replacing commercial fertilizers (NPKs) with biochar. Furthermore, secondary data about the amount of material used and the energy consumption for the process is obtained from the journal [12]. Then, emission factor data was collected from each energy and component used in the LCA analysis that can emit GHG emissions.

a. Plantation stage

As an assumption, the production of 1 ton of CPO needs 5 tons of FFB, which means the yield of CPO products is 20% of the needs of FFB [14]. In the plantation stage, fertilization is usually carried out 2 to 3 times a year to meet the nutrient consumption for the growth process of Palm Oil plants [15]. In this research, The NPK fertilizer was assumed to be used consisting of 105 kg N/ha, 70 kg P/ha, and 204 kg K/ha [16]. This amount is selected based on the average of several fertilizer uses in Indonesia and Malaysia. In this study, the land area used for the plantation process is 0.263 Ha, thus the amount of NPK fertilizer will be consumed with the following data: for scenario 1 - 27.615 kg N; 18.41 kg P; 53,652 kg K.

The scope for energy consumption analysis covers the energy used to produce NPK fertilizer (including the energy of transporting NPK fertilizer to the plantation area) and the production of biochar fertilizer, with the amount of 36.35 MJ/kg of NPK fertilizer used and 15 MJ/kg of biochar fertilizer, respectively. Moreover, diesel fuel for the transportation process and harvesting are determined to be the scope for energy consumption in this research. It is assumed to consume ten liters for plantation transportation (from and to the CPO and biochar industrial area) and 7 liters for harvesting equipment that requires fuels. The annual consumption of pesticides for this corps is 2.7 kg/ha [16]. Lastly, the solid waste from the Palm Oil Production will be processed in the milling stage.

b. Milling and CPO Production stage

The milling stage is the stage of processing Fresh Fruit Bunch (FFB) by grinding it to produce Crude Palm Oil (CPO) which is further processed to be Vegetable oil or other needs. In this study, Palm kernel Shells (PKS) as one of the solid wastes in the Palm Oil Industry will be used as a raw material for Biochar fertilizer production. On the other hand, Empty Fruit Bunch (EFB) waste will be used as a green fuel in the slow pyrolysis process to produce biochar fertilizer. According to [16], this study assumes 1 ton of FFB consists of 130.0 kg of Misocarp Fiber (MB)/ton of FFB, 70 kg of

PKS/ton of FFB, and 225 kg of EFB/ton of FFB. For energy consumption scope, this stage needs energy consumption for FFB grinding and steam generation for the CPO extraction process. The milling process uses screw mills inside the trasher drum which needs 104 MJ/ton of FFB [17] and the boiler requires 8,100 MJ/ton of CPO production [14]. Sari et al. (2011) stated this process also requires water to generate steam, process seed, purify the CPO and treat the sludge [18].

c. Biochar Production stage via slow pyrolysis

This final stage of this process covers the biochar fertilizer production using the PKS biomass as its main material and EFB as its fuel through the slow pyrolysis process. The PKS will be heated at a temperature of 450 ºC with 30 minutes of residence time to produce Biochar, BioCrude oil, and gas. It is assumed that the biochar yield in this study achieves 50.6% of the PKS and requires 7.59 MJ/kg PKS of energy for the slow pyrolysis process [17]. The energy consumption source comes from burning EFB, which is 2,656.5 MJ.

d. Inventories

In Inventories, energy is required to support the whole series of biochar fertilizer production processes. The consumption of materials and energy in this whole process can impact the environment due to the emission of GHGs. These impacts are calculated in this stage. At this stage, five different scenarios were observed to see the impact difference in emissions emitted when implementing biochar fertilizer in the Palm Oil Industry. Each scenario is differentiated by the reduction of Commercial fertilizers (NPK) usage in the Palm Oil Industry in the plantation stage. Each scenario will be reduced by 25% of NPK Fertilizer usage and replaced with biochar fertilizer, as follows:

- Scenario 1: 100% Commercial NPK fertilizer
- Scenario 2: 75% NPK fertilizer + 25% Biochar fertilizer
- Scenario 3: 50% NPK fertilizer + 50% Biochar fertilizer
- Scenario 4: 25% NPK fertilizer + 75% Biochar fertilizer
- Scenario 5: 100% Biochar fertilizer

e. Life Cycle Impact Analysis

In calculating the environmental impact resulting from biochar fertilizer production, several data were used, such as the Emission Coefficient (EC) obtained from databases (EFDB and JEC E3), the Emission Factor (EF) obtained from several existing research journals, and Conversion Factor (FC) as conversion to become a unit that is aligning with the environmental impact caused by each GHG emission. This FC value is obtained from the BEES (Building for Environmental and Economic Sustainability) impact method in OpenLCA software.

3 Result and Discussion

3.1 Biochar Production

This pyrolysis process produced solid, liquid and gaseous products. Biochar is a solid product from the pyrolysis process produced from lignin. The more lignin contained in the biomass residue as raw material, the more biochar was generated. Among Palm Oil biomass residues, Palm Oil Kernal Shell (PKS) appeared to have the most lignin content. The biochar production is usually carried out at a temperature of 300ºC to 450ºC, because at the higher temperature, the lignin compound in Palm Oil Kernal Shell (PKS) is depolymerized into gas, tar, and lignin monomers as a secondary reaction, so the formation of biochar will be diminished.

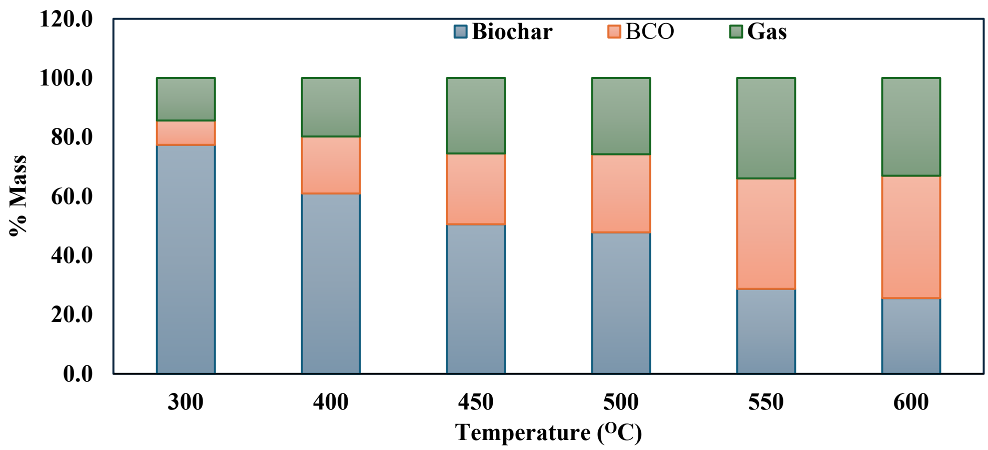

Fig. 4. Distribution of Pyrolysis Products Bar chart

Fig. 4. demonstrates the product distribution from the pyrolysis process at varied temperatures from 300ºC to 600ºC. The biochar production continues to decrease as the temperature increases. On the other hand, BCO (Bio Crude Oil) and Gas show an incline trend as the temperature increases. At lower temperatures, from 300ºC to 400ºC, Palm Oil Kernel Shell (PKS) has not reacted and turned into biochar completely because of the incomplete degradation process of the volatile component. Palm Oil Kernel Shell (PKS) usually changes into biochar at temperatures above 440ºC [19]. However, the biochar products dropped drastically from 500ºC to 550ºC, which was 19% due to the volatile compounds loss from Palm Oil Kernel Shell (PKS).

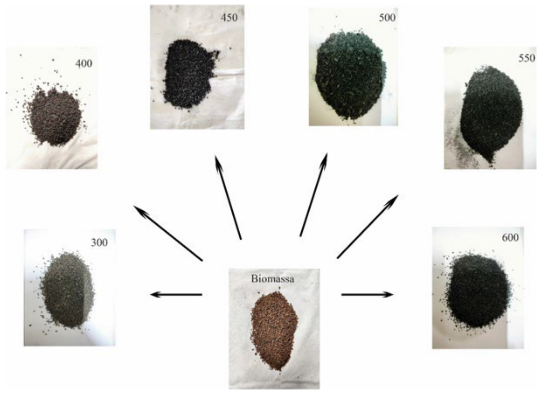

Fig. 5. The physical alteration of Palm Oil Kernel Shell (PKS) to biochar

The color transformation in the pyrolysis process was observed in **Fig. 5.** The biomass residue transformed from brown to deep black and appeared to have a reduction in terms of the biomass residue mass percentage due to the compound depolymerization. The pyrolysis process at 450ºC is considered more effective because all biomass has been converted completely into charcoal (usually above 440ºC) and it produced the most biochar products between these temperatures (300ºC to 600ºC). In addition, The depolymerization of lignin compounds occurs at 490ºC, so pyrolysis temperature at 450ºC does not turn lignin into a gas and generates a secondary reaction, resulting in the re-formation of polymer compounds in the condensation process [8].

FTIR (*Fourier Transform InfraRed*) was used to analyze the functional group properties in biochar products at the temperature of 450ºC. **Fig. 6** displays the functional group properties of biochar products due to the biopolymer degradation process of biomass residue. Several functional group properties of biochar products include alcohol group (-OH) at 3350-3400 cm^{-1}, Alkyl Aliphatic at 2850-2900 cm^{-1}, and Carboxylic at ~1700 cm^{-1}. The increasing pyrolysis temperature leads to a decrease in the intensity of the biochar product functional group. It occurs because some volatile compounds are released at higher temperatures (500ºC, 550ºC, 600ºC), thus, the macro elements such as Sulphur and Nitrogen are removed [20]. The most nitrogen content is found in biochar products at temperatures of 450ºC, making it suitable as an alternative candidate for commercial fertilizer substitution. The nitrogen component is essential for fertilizer production as it is important for soil amendment by converting it into nitrate (NO^{3-}) with the help of *Nitrosomonas* bacteria, called the nitrification process. [6]

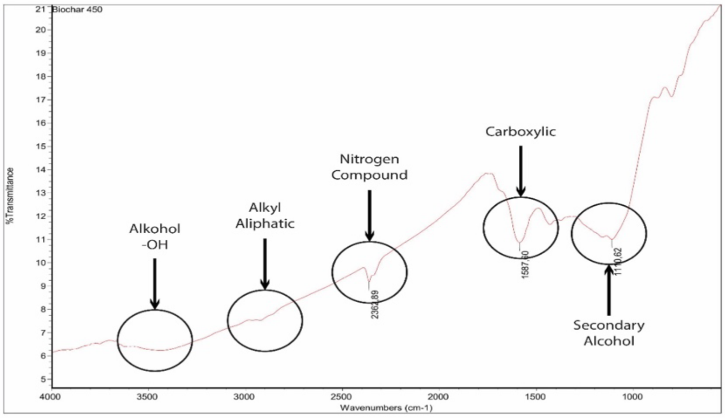

Fig. 6. FTIR analysis of Biochar product at 450°C

Morphological properties were analyzed using SEM (*Scanning Electron Microscope*) and ultimate/chemical element analysis was studied using EDS (*Energy Dispersive X-Ray Spectroscopy*). In this analysis, only biochar products at a temperature of 450°C were analyzed.

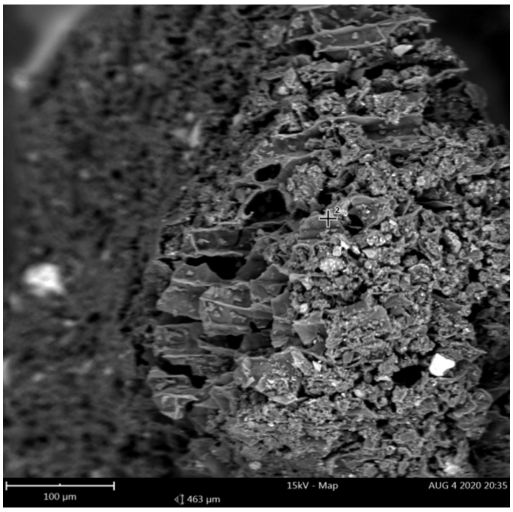

Fig. 7. Morphological properties of Biochar Product (SEM)

The morphological properties of the biochar product show nest-pore shaped with pore diameters of various ± 20-40 µm and single-double pore shapes as observed in **Fig. 7.** In addition, the pores barrier was destroyed, so it formed larger pores. The white dot ins SEM analysis demonstrates the charging phenomenon, a condition where the presence of electron rays was absorbed and accumulated at one point or area. The physical properties of biochar influence the growth of bacteria in the soil due to the nested pores that make bacteria get their source of nutrients easily. As stated by Santi et al. (2012) [21], the biochar product from Palm Oil Kernel Shell (PKS) is preferable to the bacteria due to the similarity of their environment, thus, the bacterial growth will enhance, following the maximization of the decomposition of soil minerals.

Table 1. Ultimate analysis of biochar products (EDS)

Chemical elements	%w
C	91.47
N	7.05
P	0.73
K	0.66
S	0.09

Table 2. The comparison of morphological and chemical element properties between Biochar fertilizer and commercial fertilizer (NPK)

Composition (%)	**Biochar fertilizer** [21]	**Commercial Fertilizer (NPK)**
C	25.6	-
N	1.32	[15]
P	0.07	[15]
K	0.08	[15]
Morphological properties		
Pore appearance	Nested and broad	*Honeycomb-shaped*

Table 2 shows the chemical element content of biochar products at a pyrolysis temperature of 450 ºC. Carbon content (C) was detected as much as 91.47%, meaning the carbon content is the most dominant compound in biochar products. The carbon content in fertilizer production is essential because it can increase the level of C-Organic in the soil. Moreover, it can enhance the soil's function as a CO2 absorber for global warming mitigation. Furthermore, a Nitrogen content of about 7.05% was found in the biochar products. The nitrogen content plays a crucial role in the plant fixation process as a raw material for the nitrate compounds (NO^{3-}) formation. In addition, the biochar products have their own stability ratio in the soil as shown in Table 6). The produced biochar has a C/N ratio of 19.4, indicating the biochar is in the perfect mineralization (stable) stage and has high soil mineral resistance. The high amount of C/N ratio affects the pace of Nitrosomonas bacteria in the nitrification process, the higher the C/N ratio, the more nitrate compounds are provided by the soil as an energy source for the plant growth process [21].

3.2 Life Cycle Analysis (LCA)

3.2.1 Statistical calculations and scenario analysis

The results of the LCA analysis of the predetermined boundary system show that the Milling stage and CPO production process posed the most energy demand, which is 8,620 MJ, followed by the plantation stage at 4,274.4 MJ, and the lowest was the pyrolysis stage at 2,656.5 MJ as shown in **Fig. 8.**

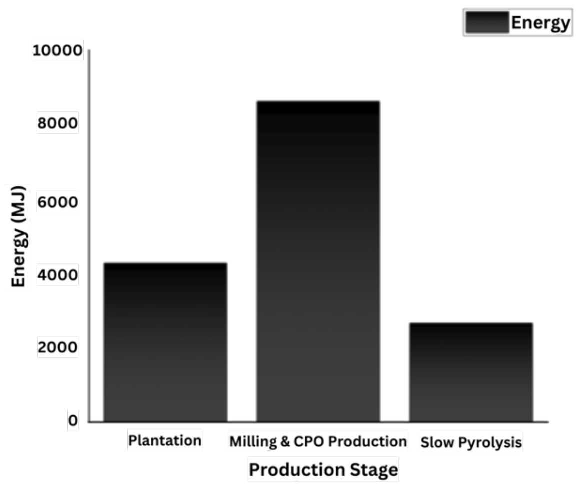

Fig. 8. Energy consumption of the Palm Oil Plantation and biochar production process

The energy consumption at the Plantation stage is divided into two parts, (i) harvesting and transportation, and (ii) the production of commercial fertilizers (NPK). Diesel fuel was chosen as a fuel for the harvesting and transportation process. Pehnelt et al. (2013) mentioned that the diesel fuel consumption for Palm Oil Tree plantation is about 15 litres/ton of CPO to 19 litres/ton of CPO [17]. In this study, the average value was chosen, so, the diesel fuel used for the plantation stage was 17 litres/ton of CPO or equivalent to 651,168 MJ. According to Hansen et al. (2007), the energy consumption for producing 74 kg of NPK fertilizer is 2,690 MJ or 36.35 MJ/kg of NPK fertilizer [14]. The energy demand in the milling stage is dominated by the CPO production process, which is around 93% or around 8,100 MJ [14] due to heat consumption by the process to heat the water (boiler) to become steam which is further used to extract CPO from Fresh Fruit bunch (FFB). Moreover, about 104 MJ/t FFB of energy is needed for the milling process, assuming 30% of the excess energy requirement [16]. The energy demand of 2,656.5 MJ in pyrolysis was needed for the biomass combustion process, the amount of energy obtained from the Harsono et al, [17] is 2.31 MJ per kilogram of EFB raw material, which means that it will be equivalent to 7.59 MJ/kg PKS. In the pyrolysis incineration process, the Empty Fruit Bunch (EFB) was used as a fuel with a calorific value of 17.97 MJ/kg [22]. This strategy was adopted to reduce greenhouse gas emissions due to its no emission factors characteristic, so it is considered to mitigate global warming (IPCC 2006). In addition, it can reduce the amount of solid waste in the Palm Oil industry.

3.2.2 Inventory flow

The inflow and outflow of energy consumption and emissions generated in the LCA analysis are divided into five scenarios. The scenario is differentiated by the amount of biochar fertilizer content mixed with NPK fertilizer. Each scenario was carried out by reducing 0%, 25%, 50%, 75%, and 100% commercial fertilizer (NPK) and replacing it with biochar fertilizers, respectively. In scenario 1, the consumption of NPK fertilizer is still at 100% value and 0% of Biochar fertilizer usage. In this research, it is assumed the distance from the CPO and biochar production area to the plantation is 10 km and the transport vehicle used is a 7-ton truck with a consumption of 2 km/liter. The energy to produce NPK fertilizer is 36.35 MJ/kg NPK [17] and emissions from the NPK fertilizer production series are 33.3 g CO_2/MJ. It was calculated from the assumption that NPK fertilizer production emits 1210.7 g CO_2/kg NPK including emissions from NPK fertilizer transportation (86.4 g CO_2/kg NPK [23]) and each type of fertilizer (N,P,K) (7,495.6 g CO_2/kg). Some amount of excess nitrogen and phosphorus minerals which usually come for 20% of NPK [17], will later react with bacteria in the soil and undergo nitrification into nitrate. In the nitrate form, some of these compounds are absorbed by plants and will undergo denitrification. However, the denitrification process is incompletely perfect, thus, some NO_2 compounds still can be released into the air [24].

The result of this study shows the reduction of energy consumption in the NPK fertilizer production process as well as emissions generated by the process. Furthermore, the biochar product was observed to be capable of absorbing CO_2. It happened because of the organic carbon content (Organic C) in biochar products, which contained 25.62% of the organic carbon content from Palm Oil Kernel Shell (PKS) [21]. The reduction of CO_2 emission achieved 1,990 g CO_2/kg organic C by the organic carbon content (Organic C) in biochar products [25]. In scenario 2, the consumption of biochar fertilizer is 24,919 kg, followed by 12,704,780 g of CO_2 emission reduction. The reduction in NPK fertilizer consumption, NPK fertilizer production, and CO_2 emission is also applied to scenarios 3 to 5, in line with the amount of NPK fertilizer replaced by biochar fertilizer.

3.2.3 Environmental Impact Analysis

GHG emissions CO_2, CH_4, N_2O, NO_2, NO, SO_2, and CO) from the whole processes of biochar production (Plantation, Milling and CPO production, Slow Pyrolysis) were mostly produced by fertilization activities for the Palm Oil Plantation stage using commercial fertilizers, fuel burning, biomass incineration, and digestion from liquid waste. *OpenLCA* software was used to analyzed the impact category of environmental issues generated from the process. The Impact of GHG emissions on NPK fertilizer replacement by biochar fertilizer can be seen in **Table 3.**

Mostly, the impact of global warming is caused by three forms of GHGs, including CO_2, CH_4, and N_2O. These gases turn out to have an impact on the rising earth's temperature [26]. In the series of biochar manufacturing processes, the Milling stage became the most influential reason causing global warming, which accounted for 71% of all processes. At this stage, the milling process and CPO production required the most fuel as shown in Table 3. The application of biochar products can reduce the impact of global warming as displayed in Table 3. The reduction of CO_2 emission was noticed regularly from scenarios 1 to 5 by the 25% substitution of NPK fertilizer with biochar fertilizer. It was detected to reduce to 0.360 Mg CO_2 eq per ton of CPO. Any 25% reduction in commercial fertilizers (NPK) consumption can reduce 0.09 Mg CO_2 eq per ton of CPO or about 3.6%.

Eutrophication and Ecotoxicity are some of the impacts caused by chemical pollution in the environment. It can trigger excessive algae growth and be toxic to the living things in the ecosystem [26]. The compounds that contribute to this phenomenon involve N_2O, NO_2, NO, and CO. These compounds are generated by fuel burning, excess nutrients in the soil due to fertilization, and pesticide utilization on plants. Therefore, Eutrophication and Ecotoxicity most often occur in the plantation stage. The use of biochar fertilizer as a substitute for NPK commercial fertilizer diminished the impact of Eutrophication and Ecotoxicity due to the reduction of chemical compounds produced from NPK fertilizer. The reduction of Eutrophication and Ecotoxicity is 10.7%, and 2.7% for each replacement of 25% of commercial fertilizers with biochar fertilizers.

Acidification is an increased acidity phenomenon in the soil caused by acid rain in an area [27]. Acid rain phenomena are strongly related to the nitrogen cycle and the detachment of SO_2 compounds into the air, therefore this impact is influenced by NO_2 and SO_2 gases. In this study, these gases were generated from the fuel combustion process (0.00012 kg/MJ) and the excessive nutrients from the consumption of commercial fertilizers, especially nitrogen, with NO_2 emission factors (0.114 kg/kg excess N) and SO_2 (0.0415 kg/kg excess N). The largest contribution to the acidification impact was detected at the Palm Oil Plantation stage, which released 36,860 H+ Moles eq per ton of CPO. The impact of acidification was reduced by 20.7% as the 25%-100% consumption reduction of commercial fertilizers (NPK) to be biochar fertilizers, regularly.

Table 3. The Impact of GHG emissions on NPK fertilizer replacement by biochar fertilizer

	Global Warming	**Acidification**	**Eutrophication**	**Ecotoxicity**
	(Mg CO_2 eq per ton CPO)	(H^+ Moles eq per ton CPO)	(g N eq per ton CPO)	(g 2,4 - Dichlorophenoxy Acetate eq per ton CPO)
Scenario 1	2,465	40.665	113,958	156,215
Scenario 2	2,375	32.244	101,676	152,012
Scenario 3	2,285	23.824	89,400	147,809
Scenario 4	2,195	15.352	77,124	143,607
Scenario 5	2,105	6.932	64,848	139,404

4.3 Life Cycle Cost Analysis (LCCA)

By approaching economic analysis data as secondary data from [28] and [17], regarding the financial flows from the Palm Oil industry and biochar product industry, the results of Life Cycle Cost Analysis (LCCA) of the production and application of biochar products from the scope of this study are shown in **Table 4**.

Table 4. Life Cycle Cost Analysis Results

Parameter	**Total**
Investment	Rp. 59,652,354,434
Remaining value	Rp. 5,965,235,443
Total fixed cost	Rp. 25,609,468,277
Total variable cost	Rp.437,812,000,000
Total cost	Rp.463,422,000,000
Total revenue	Rp.489,160,000,000
NPV	Rp. 11,106,245,910
B/C ratio	1.055
Payback Period (Year)	1.881
Break Even Point (%)	49.87
Internal rate of Return (%)	44.22

For the calculation of Life Cycle Cost Analysis, this study used several assumptions as shown in **Table 5**. Firstly, the remaining value is 10% of the total investment. The remaining value is the remaining price of the goods in the production period of 10 years [17]. Next, the total fixed cost value covers the purchasing cost of the land field and the construction of CPO and biochar production facilities. Meanwhile, the variable cost value includes the capital cost for raw materials (including commercial fertilizers), the wage for manpower, electricity and fuel costs from the CPO and biochar production process. Lastly, the interest rate of the bank investment is 12% [28]. The selling price for biochar products is Rp. 229,100 per ton [17] and the selling price for CPO is Rp. 8,149,000 per ton [28].

The payback period is the time period (generally in years) in which the industry begins to make a profit. In this study, the payback period of this industry was 1 year and 9 months after the factory construction period (10 years). The IRR value obtained was 44.22%, indicating this factory is feasible to establish with an interest rate of 12%. The BEP value of 49.87% is in accordance with the BEP value range for a factory, which ranges from 40% to 60%. The reduction of commercial fertilizers (NPK) consumption absolutely reduces the purchasing cost of fertilizers. Table 6 displays the reduction in variable costs due to the consumption reduction of commercial fertilizers (NPK) by 25% per scenario. As an assumption, the purchasing cost of fertilizer is 2% of the total variable cost used. Therefore, a 25% consumption reduction of commercial fertilizers (NPK) will reduce the capital costs by 0.5%.

Table 5. Variable *cost reduction*

Scenario	Variable Cost	
Scenario 1	Rp.	437,812,000,000
Scenario 2	Rp.	435,623,000,000
Scenario 3	Rp.	433,434,000,000
Scenario 4	Rp.	431,245,000,000
Scenario 5	Rp.	429,056,000,000

4 Conclusion

The production of biochar products using slow pyrolysis includes the process of decomposition and carbonization of biopolymer compounds from biomass residue. The biochar products are produced less at the higher pyrolysis temperature due to the alteration of biopolymer compounds in the biomass residue into gases and produce bio-oil during the condensation process. In this study, biochar fertilizer products are pyrolyzed at 450ºC and obtain a high carbon content of 91.47%w and a fairly stable C/N ratio of 12.97, indicating the biochar products can maintain the mineral content of the soil and are able to increase the amount of soil Organic C as a medium for absorbing CO_2 emission in the atmosphere. In addition, the morphological structure of biochar products like nested pores turns out to be a beneficial feature for the enhancing growth of microbes in the soil, thus, the production of plant nutrients in the soil (Nitrate) will be abundant and lead to better plant growth. The use of commercial fertilizers generated GHG emissions coming from the production of fertilizers themselves. As a result of the LCA analysis using OpenLCA, reducing the amount of commercial fertilizer consumption and substituting it with biochar fertilizer can reduce the environmental issues. The GHG emission can be reduced by up to 20% by replacing the NPK fertilizer with the biochar fertilizer.

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