

# LIFE CYCLE ASSESSMENT OF PALM OIL WASTE BIOCHAR AS A PARTIAL CEMENT REPLACEMENT IN CONCRETE PRODUCTION IN MALAYSIA

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## Abstract

As the environmental impact of construction materials faces increased scrutiny, sustainable alternatives are garnering interest. Biochar emerged as a potential candidate for partially replacing cement in construction applications. Life cycle assessment (LCA) evaluates the environmental impacts of products, processes, and services throughout their life cycle, and identify environmental improvement opportunities. This study provides a comprehensive LCA of biochar produced from empty fruit bunches and palm kernel shells as a partial cement replacement, aiming to evaluate its environmental performance across various life cycle stages. The research includes five scenarios: 4% biochar from empty fruit bunches with pyrolysis at 500°C and 455°C, 4% biochar from palm kernel shells with pyrolysis at 500°C and 409°C, and without biochar used. This study has a cradle-to-gate approach, analysing the environmental impacts of biochar production, transportation, incorporation into cement, and the resulting concrete's life cycle. The LCA is conducted using OpenLCA software and the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts TRACI for life cycle impact assessment (LCIA). The study concludes that palm oil waste biochar as a partial cement replacement reduces greenhouse gas emissions, with 4% palm kernel shell biochar pyrolysed at 409°C showing the best results among all scenarios with the emissions of carbon dioxide gas lesser by 0.474kg CO<sub>2</sub>-Eq.

## List of Notations

<i>LCA</i> is the life cycle assessment	<i>GWP</i> is the global warming potential
<i>LCI</i> is the life cycle inventory	<i>AP</i> is the acidification potential
<i>LCIA</i> is the life cycle impact assessment	<i>EP</i> is the eutrophication
<i>CO<sub>2</sub></i> is the carbon dioxide	<i>PO</i> is the photochemical oxidation
<i>EFB</i> is the empty fruit bunch	<i>HH</i> is the human health
<i>PKS</i> is the palm kernel shell	

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## Keywords:

Biochar, Cement production, Cement replacement, Empty fruit bunch, Life cycle assessment, Palm kernel shell

## 1.0 INTRODUCTION

Concrete is one of the most popular materials in the construction industry (Ding *et al.*, 2016). To reduce carbon dioxide (CO<sub>2</sub>) emissions during concrete production, the industry is exploring the use of palm oil waste biochar as a partial replacement for cement. The cement industry is a significant source of CO<sub>2</sub> emissions, releasing about 900 kg of CO<sub>2</sub> per ton of cement produced (Benhelal *et al.*, 2013). As cement is a key component in concrete, its production indirectly contributes to CO<sub>2</sub> emissions during concrete production.

In 2019, global palm oil production exceeded 74.8 million tonnes, accounting for roughly 41.37% of the world's vegetable oil supply (Ritchie and Roser, 2021). Palm oil is used in various sectors, including food (68%), consumer goods (27%), and bio-energies (5%) (Ritchie, 2020). The integrated biorefinery concept in the palm oil industry shows promise by using oil palm biomass to produce bio-based products (Mora-Villalobos *et al.*, 2023). Activated carbons, which are effective at capturing CO<sub>2</sub>, can be derived from biochar, an inexpensive source. Oil palm biomass, with a carbon content ranging from 42.7% to 57.9%, including 3.5–27% fixed carbon, is a viable source for biochar production (Zakaria *et al.*, 2023). Therefore, using palm

oil waste biochar as a partial cement replacement in concrete production is a promising sustainability strategy.

Traditional concrete production methods are associated with significant carbon emissions and environmental concerns, contributing to global climate change and environmental degradation. Concrete production's high carbon dioxide emissions are mainly due to the energy-intensive cement production process and the transportation of raw materials. Additionally, disposing of palm oil waste causes environmental issues, including air and water pollution, soil degradation, and habitat destruction. The transportation of palm oil waste biochar from rural production areas to urban concrete production facilities also contributes to carbon emissions, which can offset the environmental benefits of using biochar.

To address these challenges, there needs to be a shift towards lower carbon emissions in concrete production. Integrating palm oil waste biochar as a cement substitute can help to reduce carbon emissions from both concrete production and waste management. However, challenges such as optimising biochar properties, ensuring compatibility with existing concrete mixtures, and assessing the environmental

impact of biochar incorporation must be addressed (Guspa *et al.*, 2018). This research aims to evaluate the feasibility and environmental implications of using palm oil waste biochar as a partial cement replacement in concrete production, focusing on reducing carbon emissions and managing waste in the construction industry.

The study aims to conduct a comprehensive life cycle assessment (LCA) of palm oil waste biochar as a partial cement replacement in concrete production in Malaysia. It evaluates the environmental impacts associated with the entire lifecycle of palm oil waste biochar, from production to its incorporation into concrete mixes. The study also aims to provide recommendations for optimising the environmental performance of palm oil waste biochar as a cement replacement and promote its use in concrete production in Malaysia. The intended recipients of this research include construction engineers, cement and concrete producers, and material suppliers and manufacturers.

Conducting a LCA of palm oil waste biochar as a partial cement replacement in concrete production in Malaysia is significant as it addresses critical environmental and economic challenges while promoting sustainable development in the construction industry. By assessing the entire life cycle of palm oil waste biochar, from production to incorporation into concrete mixes, the LCA can quantify the environmental benefits of using biochar as a partial cement replacement. This includes impacts such as global warming potential (GWP), acidification potential (AP), eutrophication (EP), photochemical oxidation (PO), and human health (HH) compared to traditional concrete production methods. Understanding these impacts is crucial for mitigating environmental degradation and advancing sustainable practices.

## 2.0 LIFE CYCLE ASSESSMENT CONCEPT

To guide the utilisation of palm oil waste biochar as cement replacement among stakeholders in the construction industry, it is essential to conduct a Life Cycle Assessment (LCA) study on the biochar in concrete production. These outcomes encompass global warming potential (GWP), acidification potential (AP), eutrophication (EP), photochemical oxidation (PO), and human health (HH).

LCA studies necessitate a collection of data to quantify the extent of these outcomes, known as the life cycle inventory (LCI). Each study focuses on distinct stages of a material's lifespan, defined by system boundaries. These delineations specify different phases, as for "cradle-to-gate," which covers the extraction of raw materials up to production. Whereas for "cradle-to-grave," encompasses extraction for production to the end of the material's lifespan. Additionally, "cradle-to-cradle" denotes extraction for production till the material is recycled and reused as raw material for production again. However, in this study, cradle-to-gate is only be considered.

### 2.1 LCA on Biochar

Biochar, a carbon-rich material produced through the thermal decomposition of organic biomass, has gained significant interest for its diverse applications in agriculture, environmental restoration, and carbon sequestration (Lehmann *et al.*, 2015).

This study delves into biochar's concept, production methods, properties, and its role in addressing environmental challenges, with a particular focus on palm oil waste biochar. Biochar is created through pyrolysis, where biomass is heated in a low-oxygen environment. This ancient technique, used historically to enhance soil fertility, is now recognised for its broader potential. Biochar can be derived from various biomass sources like crop residues, wood chips, and organic waste. The pyrolysis process, involving temperatures from 350°C to 700°C, converts volatile organic compounds into gases, leaving a carbon-dense residue. The resulting biochar's properties—such as high permeability, large surface area, and high carbon content—depend on factors like feedstock type, pyrolysis conditions, and post-production treatments. These properties endow biochar with excellent adsorption capacity, water retention ability, and soil enhancement capabilities. Notably, biochar is stable in soil, potentially sequestering carbon for centuries to millennia (Li *et al.*, 2023).

Palm oil waste biochar, a byproduct of the palm oil industry, represents a sustainable innovation in waste management and environmental conservation. Amid growing concerns about waste disposal and climate change, palm oil waste biochar offers a solution that addresses waste management, carbon sequestration, and soil enrichment. In agriculture, it enhances soil quality by improving fertility, water retention, and nutrient availability, reducing the need for chemical fertilisers. Its porous nature allows it to store water and essential nutrients, creating optimal conditions for plant growth. Additionally, its carbon sequestration potential contributes to reducing greenhouse gas emissions, aligning with global climate change mitigation efforts. Beyond agriculture, palm oil waste biochar is used in wastewater treatment, renewable energy production, and carbon capture technologies, highlighting its versatility and importance in sustainable development. The use of biochar, including palm oil waste biochar, offers numerous benefits such as soil improvement, waste valorisation, and carbon sequestration (Guspa *et al.*, 2018). By converting organic waste into a valuable resource, biochar production supports circular economy principles and reduces environmental pollution. However, challenges like feedstock availability, scalability, and market acceptance need to be addressed to fully realise biochar technology's potential.

### 2.2 LCA on Concrete

Concrete is fundamental to modern construction, used globally due to its strength, durability, and versatility (Nilimaa, 2023). It is essential for various infrastructure projects, including skyscrapers, highways, and dams. Despite its benefits, concrete's environmental impact necessitates an evaluation of its sustainability using Life Cycle Assessment (LCA) methodologies. Concrete is made from aggregates (sand and gravel), cement, and water, forming a solid matrix through hydration. This composition makes it durable, fire-resistant, and cost-effective, contributing to its widespread use. It is because concrete production has significant environmental consequences, primarily from raw material extraction and processing, especially cement (Nilimaa, J. 2023). Cement production involves the calcination of limestone, which

is energy-intensive and emits substantial carbon dioxide (CO<sub>2</sub>). Additionally, extracting aggregates disturbs land and requires energy-intensive processing, further impacting the environment. LCA of concrete considers factors affecting its sustainability, including raw material choices, production methods, transportation, and waste management. Using supplementary cementitious materials like fly ash, slag, and soil can reduce the carbon footprint by partially substituting cement. Innovations in concrete mix design, such as recycled aggregates and optimised cement content, can also significantly lower environmental impacts without sacrificing performance.

### 3.0 LCA METHODOLOGY

The LCA for materials adhere to the guidelines set forth in ISO 14040 and ISO 14044 standards. These standards outline LCA as the systematic gathering and evaluation of inputs, outputs, and potential environmental repercussions associated with a product system. The LCA process comprises four distinct stages: goal and scope definition, life cycle inventory, impact assessment, and interpretation, as depicted in Figure 1 below.

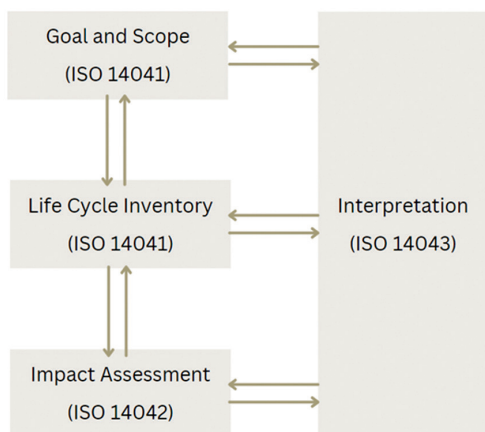


Figure 1: Life cycle assessment framework

#### 3.1 Life Cycle Inventory Analysis

The second stage of LCA comprises compiling and quantifying data regarding the product's inputs and outputs throughout its life cycle or a specific process. All gathered data are shown in Table 1 Life Cycle Inventory Data. This inventory data is inputted into the OpenLCA software to represent the inputs and outputs of individual processes. Data collected from studies has been incorporated into this research, as displayed in Table 1. The utilisation of data from all the sources aims to ensure the completeness of the LCI data, thereby enabling a more dependable assessment for the developed scenarios. The emissions from diesel and from EFB and PKS belongs to midpoint category while the emissions from cement and concrete belongs to endpoint category.

#### 3.2 Life Cycle Impact Assessment

The Environmental Impact Assessment (LCIA) method employed in this study is the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) method. TRACI aims to measure and assess the possible environmental impacts associated with various

Table 1: Life cycle inventory data

Inventory	Value	Unit	Reference
<b>Average transportation distance</b>			
From Mill to Biochar Production Plant	69.94	km	
From Biochar Production Plant to Concrete Batching Plant	30.63	km	
From Cement Batching Plant to Concrete Batching Plant	31.33	km	
<b>Transportation by Truck</b>			
Load	7.5-12	t	
Diesel Consumption	0.00667645	MJ/km	(Arshad, 2019)
<b>Emissions from diesel</b>			
CO <sub>2</sub>	5.79495134	kg/MJ	(Mustapa & Bekhet, 2016)
CO	0.003889	kg/MJ	(Anon, 1996)
HC	0.0009723	kg/MJ	(Anon, 1996)
NO	0.005004	kg/MJ	(Anon, 1996)
<b>EFB LCI</b>			
Electricity	92.9824564	kWh/kg	(Nasrin <i>et al.</i> , 2017)
Drying	278.947368	MJ/kg	(Nasrin <i>et al.</i> , 2017)
<b>Emissions from EFB</b>			
CO	0.00151047	kg	(Chan <i>et al.</i> , 2016)
CO <sub>2</sub>	0.01428132	kg	(Chan <i>et al.</i> , 2016)
CH <sub>4</sub>	0.00305622	kg	(Chan <i>et al.</i> , 2016)
<b>PKS LCI</b>			
Electricity	38	kWh/kg	(Rusdianasari <i>et al.</i> , 2022)
Drying	1200	kWh/kg	(Rusdianasari <i>et al.</i> , 2022)
<b>Emissions from PKS</b>			
CO	0.0227454	kg	(Qureshi <i>et al.</i> , 2022)
CO <sub>2</sub>	0.02454545	kg	(Qureshi <i>et al.</i> , 2022)
CH <sub>4</sub>	0.0348	kg	(Qureshi <i>et al.</i> , 2022)
<b>Cement LCI</b>			
Limestone	65	%	(Sutar <i>et al.</i> , 2021)
Clay	20	%	(Sutar <i>et al.</i> , 2021)
Shale	10	%	(Sutar <i>et al.</i> , 2021)
Gypsum	5	%	(Sutar <i>et al.</i> , 2021)
<b>Emissions from Cement</b>			
CO <sub>2</sub>	0.9	kg	(Ali <i>et al.</i> , 2011)
NO <sub>2</sub>	3000	mg	(Ali <i>et al.</i> , 2011)
NO	3000	mg	(Ali <i>et al.</i> , 2011)
O <sub>2</sub>	0.42	kg	(Ali <i>et al.</i> , 2011)
<b>Concrete LCI</b>			
Cement	15	%	
Water	15	%	
Aggregate	70	%	
<b>Emissions from Concrete</b>			
CO <sub>2</sub>	0.93	kg	(Keegan R., 2020)
CO	0.00021	kg	(Gursel & Ostertag, 2016)
NO <sub>2</sub>	0.00136	kg	(Gursel & Ostertag, 2016)
NO	0.00136	kg	(Gursel & Ostertag, 2016)
NMVOcs	0.00024	kg	(Gursel & Ostertag, 2016)
SO <sub>2</sub>	0.00199	kg	(Gursel & Ostertag, 2016)

human activities, products, and processes, particularly focusing on chemical and other pollutants that may contribute to environmental degradation. It provides a framework for assessing a wide range of environmental impact categories. TRACI methodology considers both midpoint and endpoint impact categories. Midpoint impact categories represent specific environmental stressors or pollutants, such as emissions of greenhouse gases or air pollutants. Endpoint impact categories, on the other hand, reflect broader environmental outcomes, such as human health impacts or ecosystem damage. Table 2 below shows the unit of each TRACI environmental impact categories.

Table 2: TRACI environmental impact categories

Indicator	Unit
Acidification Potential (AP)	Moles of H+-Eq
Eutrophication Potential (EP)	kg N
Global Warming Potential (GWP)	kg CO2-Eq
Photochemical Oxidation (PO)	kg NOx-Eq
Human Health (HH) (respiratory effects, average)	kg PM2.5-Eq

### 3.3 Modelled Scenarios

As part of this research, five scenarios will be conducted and compared which includes use of 4% of biochar from empty fruit bunch with pyrolysis process at 500°C and 455°C, 4% of biochar from palm kernel shell with pyrolysis process at 500°C and 409°C, and without biochar used. The evaluation of life cycle assessment (LCA) in this study is conducted based on the process shown in Figure 2.1 and Figure 2.2.

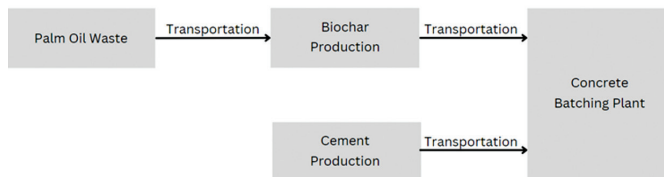


Figure 2.1: Modelled scenario with biochar

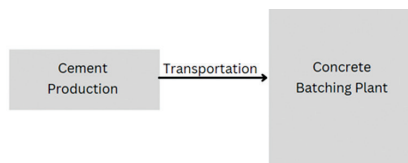


Figure 2.2: Modelled scenario without biochar

Table 3 shows the locations of palm oil mills, biochar plants, cement production plants, and concrete batching plants are chosen and taken the average distance from one point to another point.

By averaging the distance of all the locations, Table 4 presents the average distances for palm oil mill to biochar plant, biochar plant to concrete batching plant, and cement production plant to concrete batching plant. The average distance is utilised in the LCA investigation conducted in this study.

### 4.0 SCENARIOS OVERVIEW

Figure 3.1 to Figure 3.5 show the five scenarios that have been developed in OpenLCA software to generate environmental impact assessment. In total of 5 scenarios will be conducted and compared which includes use of 4% of biochar from empty

Table 3: Locations of palm oil mills, biochar plants, cement production plants, and concrete batching plants

Location	Address
Palm oil mill	Jalan Tok Mujir, Kampung Sungai Buaya, 42700 Banting Selangor
Palm oil mill	Batu 37, Jalan Raja Musa, 45600 Batang Berjuntai Selangor
Palm oil mill	Batu 24, Jalan Kuala Selangor, 47000 Sungai Buloh Selangor
Palm oil mill	LOT 334 Jalan Kepong, MUKIM, 45600 Batang Berjuntai Selangor
Biochar plant	Stesen Penyelidikan Usahama MPOB-UKM, Kajang Selangor
Biochar plant	C-01-11, Jalan Sri Kenari 12, Taman Sri Kenari, 43000 Kajang Selangor
Biochar plant	8942, Jalan Telok Gong, Kampung Telok Gong, 42000 Klang Selangor
Biochar plant	Jalan SP 2/1, Taman Serdang Perdana, Seri Kembangan Selangor
Cement production plant	8, Jalan Putra Prima 5/12, 47130 Puchong, Selangor
Cement production plant	207, Jalan Subang 6, Taman Perindustrian Subang, 47500 Subang Selangor
Cement production plant	No. 2, Jalan Kilang 51/206, Pjs 51, 46050 Petaling Jaya, Selangor
Cement production plant	Kawasan Industri Kampung Jaya Sungai Buluh, 47000 Sungai Buloh, Selangor
Concrete batching plant	Jalan Dua, Chan Sow Lin, 55200 Kuala Lumpur
Concrete batching plant	17, Jalan Tiga, Chan Sow Lin, 55200 Kuala Lumpur
Concrete batching plant	1558, Jalan Kusta, Kawasan Industri Kampung Jaya, 47000 Sungai Buloh, Selangor
Concrete batching plant	Jalan Perindustrian Balakong, Taman Balakong Jaya, 43000 Seri Kembangan Selangor

Table 4: Average distance for each route

Route	Average Distance (km)
Palm Oil Mill to Biochar Plant	69.94
Biochar Plant to Concrete Batching Plant	30.63
Cement Production Plant to Concrete Batching Plant	31.33

fruit bunch with pyrolysis process at 500°C and 455°C, 4% of biochar from palm kernel shell with pyrolysis process at 500°C and 409°C, and without biochar used.

For scenarios with biochar used, the process starts with transportation of palm oil waste from palm mills and transported to biochar mill to undergo pyrolysis process to produce biochar. Different temperatures are taken into account during pyrolysis process as different temperatures of pyrolysis would produce different amount of greenhouse gases and different amount of energy required. The biochar produced will then be transported to concrete batching plant to act as partial cement replacement during concrete production. Cement production will take place at cement production plant and transport to concrete batching plant for final stage. During concrete production, 4% of cement will be replaced with biochar during concrete production to produce concrete with lower greenhouse gas emissions.

As for scenario without the use of biochar, the normal concrete production is adhered by starting with concrete production at concrete production plant. The produced concrete

will then be transported to concrete batching plant to produce concrete. Results are obtained for making better comparison of impact categories of global warming potential (GWP), acidification potential (AP), eutrophication (EP), photochemical oxidation (PO), and human health (HH) between used of biochar and without biochar.

**4.1 TRACI Analysis**

With the 5 scenarios modelled, two different comparisons are produced which is with and without transportation considered to provide a more detail results. With this comparison, impact of materials production and impact due to transportation can be

shown clearly. Table 5.1 and Table 5.2 summarise the TRACI analysis results of each impact category with all 5 scenarios. Figure 4.1 and Figure 4.2 show the relative results with and without transportation.

Each impact categories assessed by TRACI is shown below for results without transportation in order to identify clearly how each scenario performs. Global Warming Potential (GWP) assess the environmental impact of greenhouse gas emissions relative to carbon dioxide (CO<sub>2</sub>), Acidification Potential (AP) evaluates emissions of sulphur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>), Eutrophication Potential (EP) evaluates capacity to induce eutrophication, characterised by the influx of surplus nutrients including nitrogen and phosphorus, Photochemical Oxidation (PO) evaluates reaction of pollutants including nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds (VOCs) under sunlight, and Human Health (HH) (respiratory effects, average) assess the potential health impacts of air pollutants comprising particulate matter (PM), ozone (O<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), and sulphur dioxide (SO<sub>2</sub>).

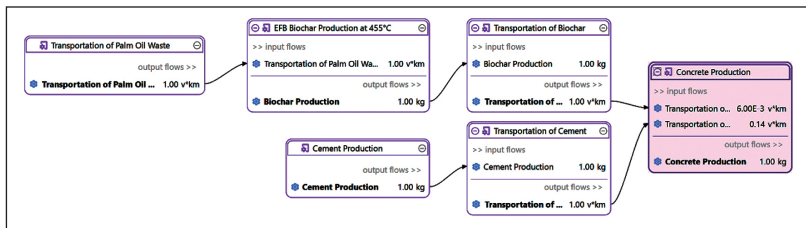


Figure 3.1: OpenLCA model: scenario of 4% empty fruit bunch at 455°C pyrolysis

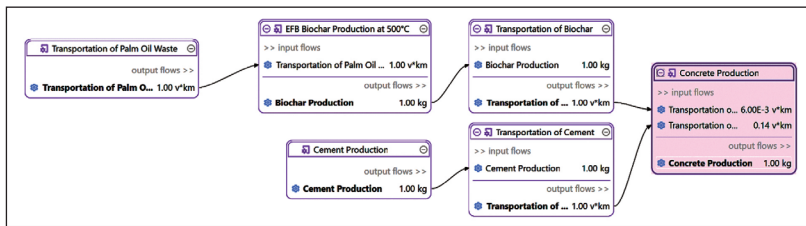


Figure 3.2: OpenLCA model: scenario of 4% empty fruit bunch at 500°C pyrolysis

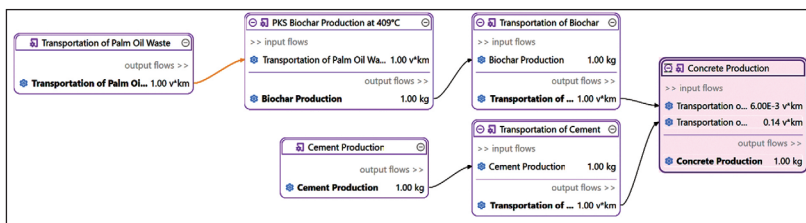


Figure 3.3: OpenLCA model: scenario of 4% palm kernel shell at 409°C pyrolysis

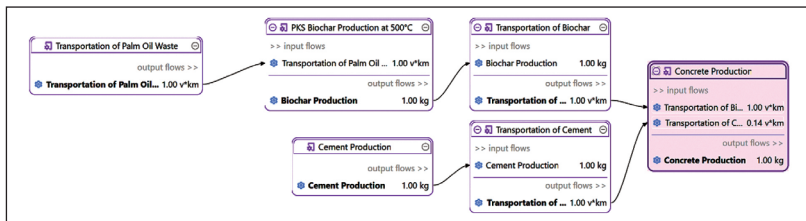


Figure 3.4: OpenLCA model: scenario of 4% palm kernel shell at 500°C pyrolysis

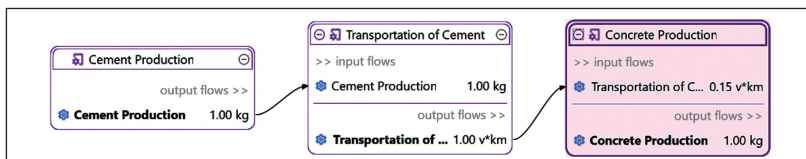


Figure 3.5: OpenLCA model: scenario of 100% cement

**5.0 RESULTS ANALYSIS**

Based on Figure 4.1, by setting 100% to the maximum result for each indicator, normal concrete production as the control study shows 100% on all impact categories. This clearly shows that the use of biochar as partial cement replacement indeed lowers the impact of greenhouse gas emissions during concrete production. For acidification potential, the use of empty fruit bunch biochar for both 455°C and 500°C produced a result of 80.65% and 87.76% respectively whereas for the use of palm kernel shell biochar for both 409°C and 500°C produced a result of 70.87% and 87.76% respectively. The greatest difference in percentage is between normal concrete production and the use of palm kernel shell biochar for both 409°C with difference of 29.17%.

Following the environmental impact of eutrophication potential, normal cement production remains 100% while other four scenarios ranging in between 60% to 80%. The use of empty fruit bunch biochar for both 455°C and 500°C shows a result of 70.42% and 75.61% respectively while the use of palm kernel shell biochar for both 409°C and 500°C shows a result of 65.21% and 75.61% respectively. The results for global warming potential and photochemical oxidation for scenarios with biochar used performs around the same with a small difference within 3%. Assessing human health impact, both biochar with 500°C has a percentage of 94.94% while the use of empty fruit bunch biochar for 455°C has a percentage of 86.69% and the use of palm kernel shell biochar for 409°C has a percentage of 74.21%.

Table 5.1: TRACI analysis without transportation

	Concrete Production	EFB Concrete Production at 455°C	EFB Concrete Production at 500°C	PKS Concrete Production at 409°C	PKS Concrete Production at 500°C	Unit
AP	1.979e-1	1.596e-1	1.736e-1	1.402e-1	1.736e-1	Moles of H+-Eq
EP	1.075e-4	7.538e-5	8.094e-5	6.980e-5	8.094e-5	kg N
GWP	1.382e+0	9.894e-1	1.073e+0	9.081e-1	1.078e+0	kg CO2-Eq
PO	2.420e-3	1.705e-3	1.831e-3	1.580e-3	1.833e-3	kg NOx-Eq
HH	5.906e-4	5.120e-4	5.607e-4	4.383e-4	5.607e-4	kg PM2.5-Eq

Table 5.2: TRACI analysis with transportation

	Concrete Production	EFB Concrete Production at 455°C	EFB Concrete Production at 500°C	PKS Concrete Production at 409°C	PKS Concrete Production at 500°C	Unit
AP	1.979e-1	1.837e-1	1.978e-1	1.644e-1	1.978e-1	Moles of H+-Eq
EP	1.075e-4	1.021e-4	1.076e-4	9.651e-5	1.076e-4	kg N
GWP	1.382e+0	1.318e+0	1.401e+0	1.240e+0	1.410e+0	kg CO2-Eq
PO	2.420e-3	2.308e-3	2.434e-3	2.185e-3	2.438e-3	kg NOx-Eq
HH	5.906e-4	5.397e-4	5.884e-4	4.659e-4	5.884e-4	kg PM2.5-Eq

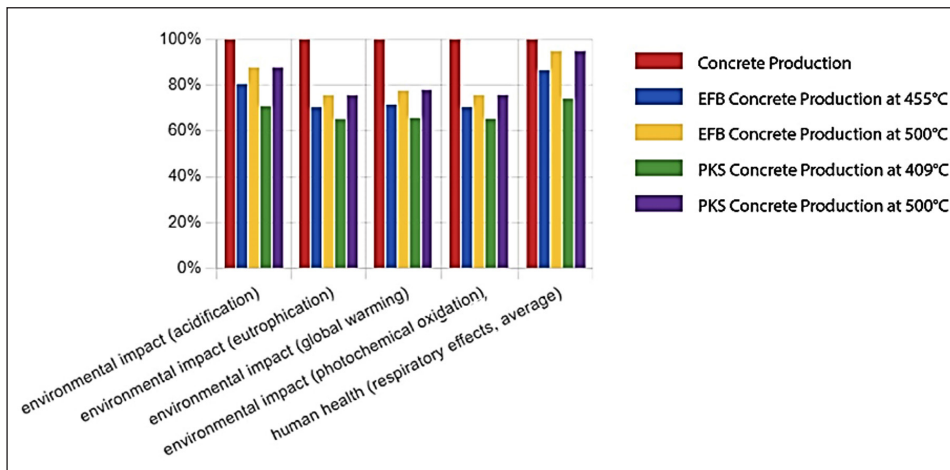


Figure 4.1: Relative results without transportation

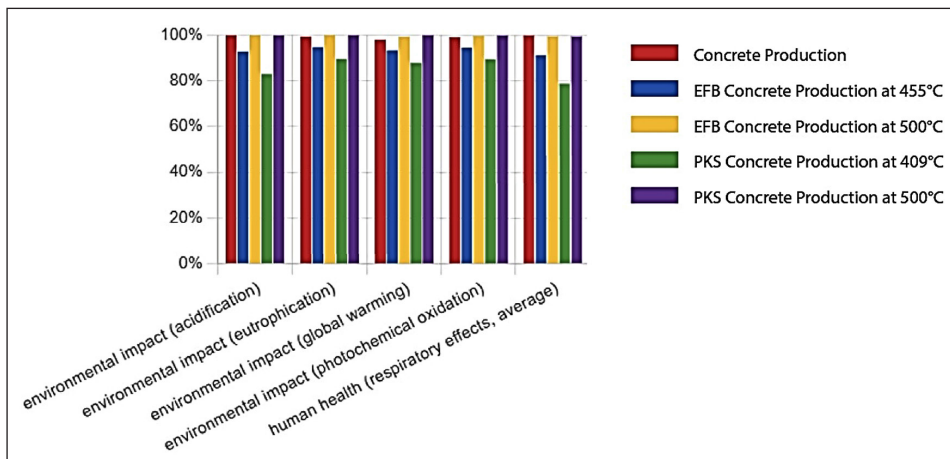


Figure 4.2: Relative results with transportation

Based on the results produced, the use of palm kernel shell biochar for 409°C shows the lowest impact of greenhouse gases emissions among all other scenarios with 29.16% lower for acidification potential, 35.07% lower for eutrophication potential, 34.3% lower for global warming potential, 34.71% lower for photochemical oxidation, and 25.79% lower for human health with transportation not taken into consideration compared with normal concrete production. With transportation

taken into consideration, the impact of greenhouse gases emissions is lowered by 16.93% for acidification potential, 10.22% for eutrophication potential, 10.27% for global warming potential, 9.71% for photochemical oxidation, and 21.11% for human health compared with normal concrete production.

**6.0 OVERALL IMPACT**

Based on Table 5.1, the amount of each impact categories for all five scenarios are shown side by side for easier comparison. Based on the result, global warming potential shows the higher impact among all other categories. This can be explained by the environmental impact of greenhouse gas emissions relative to CO<sub>2</sub> is the highest among all other greenhouse gases. With 1kg of concrete produced, 1.382kg CO<sub>2</sub>-Eq is produced for normal concrete production where the CO<sub>2</sub> emissions includes cement production. As for the other four scenarios, the emission of CO<sub>2</sub> produced is 0.99kg CO<sub>2</sub>-Eq, 1.073kg CO<sub>2</sub>-Eq, 0.908kg CO<sub>2</sub>-Eq, and 1.078kg CO<sub>2</sub>-Eq respectively.

The subsequent greater impact would be acidification potential. All five scenarios ranging from 1.403e-1 moles of H+-Eq for the use of empty fruit bunch biochar for 455°C to 1.978e-1 moles of H+-Eq for normal concrete production. The other three impact categories which includes eutrophication potential, photochemical oxidation, and human health impact has very small value as shown in Table 5.1.

By comparing Table 5.1 and Table 5.2, it clearly shows that the impact of transportation towards the impact categories is great. The value for all four use of biochar scenarios increases significantly. This is mainly due to the transportation of palm oil waste from palm oil mill to biochar plant has an average of 69.94km where the emissions of greenhouse gases from truck. The difference of GWP values between with and without transportation for the use of empty fruit bunch biochar for 455°C is 0.329kg CO<sub>2</sub>-Eq and for 500°C is 0.328kg CO<sub>2</sub>-Eq and for the use of palm kernel shell biochar for both 409°C and 500°C is 0.332kg CO<sub>2</sub>-Eq. The difference of AP values between with and without transportation for the use of empty fruit bunch biochar for 455°C is 0.241 moles of H<sup>+</sup>-Eq and for 500°C is 0.242 moles of H<sup>+</sup>-Eq and for the use of palm kernel shell biochar for both 409°C is 0.242 moles of H<sup>+</sup>-Eq and for 500°C is 0.242 moles of H<sup>+</sup>-Eq.

## 7.0 FUTURE RECOMMENDATIONS

Future research studies on biochar should focus areas that are able to maximise its potential and address existing gaps including investigation on the suitability of diverse biomass sources, including agricultural residues, municipal waste, and industrial byproducts, to produce biochar with tailored properties for specific applications. Furthermore, enhancement on pyrolysis process by studying the effects of varying pyrolysis conditions (temperature, heating rate, duration) on biochar's physical, chemical, and structural properties to optimise its performance in different uses. Study of soil-biochar interactions by conducting long-term field studies to understand biochar's impact on soil health, microbial activity, nutrient cycling, and crop productivity across different soil types and climates. Moreover, study of the efficiency of carbon sequestration by quantifying biochar's long-term carbon storage potential and its role in reducing greenhouse gas emissions, including its stability and degradation rates in various environments. Additionally, explore biochar's effectiveness in wastewater treatment, contaminant removal, and its potential in renewable energy systems, such as bioenergy production and carbon capture technologies and assess the economic feasibility, scalability, and environmental impacts of biochar production and application through lifecycle assessments (LCA) and cost-benefit analyses. Investigation of potential risks associated with biochar, such as the presence of heavy metals or polycyclic aromatic hydrocarbons (PAHs), and develop safe production and application guidelines and research on strategies to integrate biochar production into circular economy models, focusing on waste valorisation and resource efficiency. By addressing these research areas, the scientific community can unlock the full potential of biochar as a sustainable solution for agriculture, environmental management, and climate change mitigation.

## 8.0 CONCLUSIONS

The assessment on the results produced from OpenLCA software for the five modelled scenarios, palm oil waste biochar as partial cement replacement in concrete production does shows lower impact on all categories. With the results produced, it is able to identify that palm kernel shell biochar with 409°C shows the best results among all other scenarios.

However, due to incorporation of transportation, the effect of biochar as partial cement replacement is unable to perform a better result as expected. Hence, more detail study can be initiated in future to resolve the issue caused by taking account of transportation. Overall, these conclusions align with the aim of implementing palm oil waste biochar as partial cement replacement in concrete production. Justifications provided adhere to the study's objectives, encouraging the use of palm oil waste biochar in the Malaysian construction industry.

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