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Life Cyle Assessment of Activated Carbon from Waste Materials as an Adsorbent in Wastewater Treatment

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ABSTRACT

Activated Carbon (AC) has been a great alternative to reduce the cost of the process in wastewater treatment plants (WWTP) but they also have several hidden impacts on the environment. The impact assessment on the waste materials from coconut shells and wood will be identified using the Life Cycle Assessment (LCA) software approach. Through the "Cradle-to-gate" approach, activated carbon made from waste materials is produced and consumed, and its eighteen environmental effects which are fine particulate matter formation, fossil resource scarcity, freshwater ecotoxicity, freshwater eutrophication, global warming, human carcinogenic toxicity, human non-carcinogenic toxicity, ionizing radiation, land use, marine ecotoxicity, marine eutrophication, mineral resource scarcity, human health, terrestrial ecosystem, stratospheric ozone depletion, terrestrial acidification, terrestrial ecotoxicity and water consumption are assessed using the LCA software. This study aims to discover whether the choice of waste material precursors from the Activated Carbon (AC) can help to minimise environmental impacts. The study evaluates the potential benefits of using waste-derived activated carbon in wastewater treatment by comparing the environmental performance of activated carbon obtained from coconut, wood, and coal. This study is based on past studies all around the world. In thirteen of the eighteen impact categories, wood has the greatest environmental impact. Coconut shells on the other hand, has the lowest total environmental impacts, ranking first or second in fifteen among the eighteen environmental categories. The findings help in making choices for environmentally friendly wastewater treatment methods by illuminating the effects of employing waste products as an alternative source of adsorbents.

Keywords: Waste materials; activated carbon; adsorbent; OpenLCA software

INTRODUCTION

Presently, Activated Carbon (AC) is an adsorbent that has been incorporated in the water treatment process. AC, occasionally known as activated charcoal, is a type of carbon that is frequently used for a variety of purposes, including the filtration of impurities from water and air. High surface area, high surface reactivity, and high porosity make AC an efficient adsorbent. In general, a variety of carbon-rich raw materials, such as coal, coconut shells and wood, are utilised to produce activated carbon. Colourants and trace substances including chemicals could be removed from drinking water using AC. According to Korotta-Gamage and Sathasivan in 2017, the production of activated carbon, particularly the activation phase, and the extraction of raw materials have substantial adverse environmental impacts. In various fields of research, the environmental effects of AC and other water treatment techniques have been evaluated using the Life Cycle Assessment (LCA) methodology. Life Cycle Assessment

(LCA) is the methodical analysis of the possibility of environmental effects of goods or services over the course of their entire life cycle. Processes and technologies with reduced environmental impacts can be chosen with the aid of LCA. In the quest for more environmentally sustainable wastewater treatment, LCA is a useful technique to illuminate the broader environmental impact of design and operation decisions. In wastewater treatment, untreated sewage has adverse effects on society and the environment if disposed without treatment.

A thorough examination of the environmental advantages of water conservation and the environmental harm caused by water treatment is necessary. Hence, Activated Carbon (AC) has become a prominent option for treating wastewater. However, although the AC has been a great alternative to reduce the cost of the process in wastewater treatment plants (WWTP), they also have several hidden impacts on the environment. Therefore, it is crucial to identify the negative impact of the AC materials in order to choose the suitable adsorbents that have the least impact on the environment. The aim of this study is to discover whether the choice of waste material precursors from the Activated Carbon (AC) can help to minimize environmental impacts. The objectives of this study are to perform the Life Cycle Assessment (LCA) of coconut shells, wood and coal using OpenLCA software, to compare the Life Cycle Impacts Assessment (LCIA) between coconut shells, wood and coal and to investigate the performance of coconut shells, wood and coal as an adsorbent in wastewater treatment. In this study, both coal-based materials and waste materials will be assessed. Specifically, coconut shells and wood wastes will be utilized for evaluation. All the raw data that will be key in on the software is obtained based on data availability from past study around the world. The cradle-to-gate method will be used in this study where a product's whole life cycle, including the stages of manufacture, distribution and the end of production which is "gate".

Past study, (Vilen et al. 2022) use CML 2001–August 2016 method as the characterization method for potential impacts while this study use Recipe method which has eighteen parameters of impact that can be discussed. In Addition, (Arena et al. 2016) and (Gu et al. 2017) research's only computed one waste materials, coconut shells and woody biomass respectively. Existing research prefer to concentrate on individual feedstocks, frequently missing a clear and comprehensive comparison of these widely utilised materials. Hence, the environmental impact for both of the waste material has limit the findings to compare with the coal AC. Joseph et al.'s study also focuses on the sustainability of AC obtained from residual biomass in a particular application, but it may not provide a wider comparison with other AC raw materials such as coal, coconut shells, and wood. This current study, which focuses on the life-cycle assessment of AC derived from coal, coconut shells, and wood in wastewater treatment, fills a related research gap. By specifically evaluating the environmental impacts of AC obtained from various feedstocks, this study delivers an improved comprehension of the overall sustainable effects in wastewater treatment applications. This comparative LCA approach enables a more comprehensive examination of compromises and environmental performance, which aids in the process of making decisions for selecting the most environmentally sustainable adsorbent material.

This study is significant for wastewater treatment to contribute to the decision making in choosing the suitable waste materials as an adsorbent in the wastewater treatment process and analyze which activated carbon from waste materials is suitable and gives the least negative impacts on the environment. In addition, some nations are unable to pay for advanced and expensive treatment technologies. The development of novel processes and technologies with the potential to address the wastewater problem in an economical and effective manner through locally developed alternatives for treatment and reuse is necessary in this context if they are going to move forward.

METHODOLOGY

In this study approach, a procedure or work flow for identifying, processing, and analysing information on existing wastewater treatment is developed. It also aids in determining the quality and accuracy of a report's objectives.

GOAL AND SCOPE

The overall objective of the LCA study is described in the goal statement. It often discusses the study's intended use as well as any relevant environmental implications or particular environmental elements. In this study, a focus on carbon footprint, energy use, and water usage would be used to evaluate the environmental performance of various waste materials used as adsorbents in wastewater treatment. The system boundaries, life cycle stages, and functional units needed to be taken into account in the scope of this study. The boundaries of the system in (Figure 1) provide the scope of the assessment and specify which processes and procedures are included or excluded from the evaluation. The products that are under comparison represent a range of common AC options which are coal, coconut shell, and wood. The system's boundaries are just cradle to gate, or from the selection of raw materials to their transportation and use at the water treatment facility. The product's usage and end-of life stages are not included in the system boundaries because it is presumed that they are the same for all items. Identical to previous LCAs study on AC, the functional unit (FU) was determined to be an input-based FU of 1 kg of produced AC. This enables comparison of the AC with various types apart from the study's stated end-application.

ASSUMPTIONS AND LIMITATIONS IN ANALYZING LCA

The assumption and limitation in this LCA is the activated carbon evaluated are considered to be ACs that are utilised at a WWTP in Malaysia. Besides, waste ash transportation to wastewater treatment plants is excluded from assessment because its impact has been considered to be insignificant. Moreover, the transportation used in this assessment is assumed to be land transportation using trucks to transport the raw materials to the manufacturing process. The utilisation phase that is used in WWTP is not included in the system boundary as there is not enough information available about its creation. The environmental effects during use are influenced by factors including purifying effectiveness and reactivation frequency.

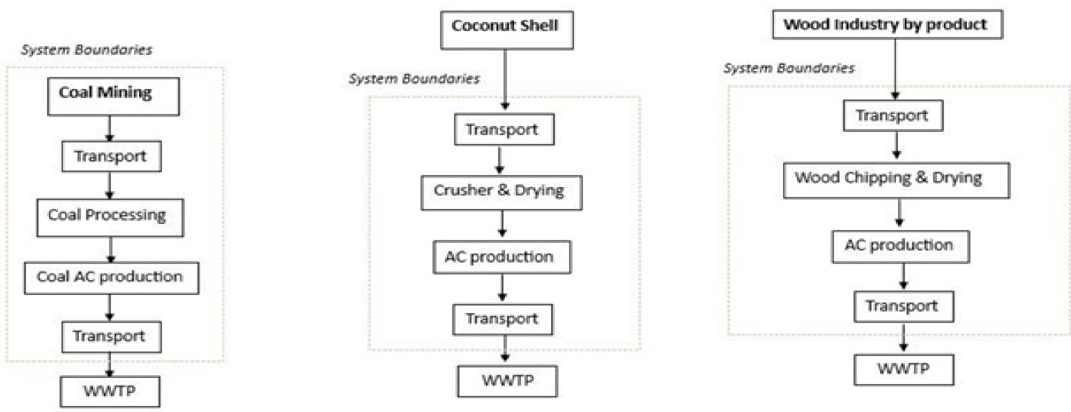

FIGURE 1. System boundaries of waste materials and coal

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LIFE CYCLE INVENTORY DATA (LCI)

The material and energy balance and carbon distribution for AC manufacturing from hard coal were calculated using Agribalyse datasets on coal AC extraction. Hard coal, natural gas, water, and power are all inputs towards the manufacture of AC (Table 1). Based on Bay et al. (2005), a bulk yield of 30%, coal is transformed into AC during the process. At 700˚C, the coal is initially carbonised, and at 800-1000˚C, it is activated. Steam is created for activation using natural gas. Based on emissions from the combustion of coal for the production of heat, Gu et al. (2017) have reported the output of the emissions. . (Table 2) shows the input and output process of activated carbon for coconut shells Crushed and dried coconut shells are used to remove almost every bit of the moisture from the waste material before being delivered to the process of carbonization. The coconut shells were projected to travel an average distance of 20 kilometres to the AC producing facility. According to estimates from Arena (2016), the crusher uses 2.16 kWh of electric energy per kg of activated carbon generated, along with the activated carbon tumble machine and crusher. In many places, wood constitutes one of the most frequent locally accessible residual raw materials. Hence, (Table 3) shows the input and output process of activated carbon for coconut shells The wood were projected to travel an average distance of 50 kilometres to the AC producing facility. The leftover wood is first dried and chipped into a consistent size. Then, a carbonization furnace has been supplied with pretreated wood waste chips. Based on the past literature by Kim in 2019, an estimated 100 litres (83 kg) of light fuel was utilised for the initial igniting and 2.5 hours of internal kiln heating. The carbonization process produced smoke and gas, which were collected and recirculated for heating. Therefore, following the kiln's initial operation, additional electricity was not needed.

TABLE 1. The Input and Output process for Coal AC

Flow	Amount	Unit
Input		
Coconut shells	6.7	kg
Electricity	2160	MJ
Transport	0.4	t*km
Water	1.5	kg
Output	Amount	Unit
Carbon dioxide	6.46	kg
Carbon monoxide	0.00244	kg
Coconut Activated Carbon	1	kg
Dust, unspecified	6.10E-05	kg
Nitrogen oxides	0.00183	kg
Nitrogen, atmospheric	0.019	kg
Oxygen	0.88	kg
Tar	0.0039	kg
Water	4.2	Kg

Source : Adapted from Gu et al. (2017)

TABLE 2. The input and output process from coconut shells AC

Flow	Amount	Unit
Input		
Coal, hard	3	kg
Electricity, high voltage	1.6	kWh
Natural gas, high pressure	3.3	m3
Transport, freight, lorry,	0.4	t*km
Water (fresh water)	12	kg
Output	Amount	Unit
Acetaldehyde	1.10E-06	kg
Acrolein	1.32E-08	kg
Arsenic	3.08E-07	kg
Benzene	2.84E-04	kg

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Flow	Amount	Unit
Beryllium	2.40E-07	kg
Biphenyl	3.75E-05	kg
Cadmium	1.48E-07	kg
Carbon dioxide, fossil	8.52	kg
Carbon monoxide, fossil	0.002041	kg
Chromium	2.11E-05	kg
Coal Activated Carbon	1	kg
Formaldehyde	1.99E-05	kg
Hydrogen fluoride	0.001489	kg
Lead	8.60E-06	kg
Manganese	2.87E-06	kg
Mercury	2.00E-06	kg
Methane, fossil	6.00E-05	kg
Naphthalene	1.95E-04	kg
Nickel	1.98E-05	kg
Nitrogen oxides	0.021362	kg
Oils, unspecified	3.27E-06	kg
Particulates	0.009672	kg
Particulates, > 2.5 um, and < 10um	0.001362	kg
Phenanthrene	1.02E-05	kg
Selenium	1.95E-06	kg
Sulfur dioxide	0.136347	kg
Suspended solids, unspecified	6.55E-06	kg
VOC, volatile organic compounds, unspecified origin	2.05E-04	kg
Waste, solid	0.031947	kg
Water	12	kg

Source : Adapted from Arena et al. (2016)

TABLE 3. The input and output process from wood AC

Flow	Amount	Unit
Input		
Crude oil	39.1	kg
Diesel	0.214	kg
Electricity	0.124	kWh
Natural gas	1.76	kWh
Water	79.1	kg
Wood chips, at farm/FR S	8.47	kg
Output	Amount	Unit
Carbon dioxide	3.19	kg
Methane	0.15	kg

continue ...

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Methane, chlorodifluoro-, HCFC-22	1.29E-05	kg
Nitrogen oxides	0.248	kg
Sulfur oxides	0.465	kg
Waste, unspecified	0.648	kg
Wastewater	3.88	m3
Wood Activated Carbon	1	kg

Source: Adapted from Kim et al. (2018)

LIFE CYCLE IMPACT ASSESSMENT (LCIA)

Utilise specific impact assessment techniques with OpenLCA's LCI data. The environmental implications of the system's inputs and outputs are quantified using these techniques, which take into account impact categories like climate change, resource depletion, human health, and ecosystem quality. In OpenLCA, the ReCiPe approach enables a thorough assessment of the environmental effects related to the life cycle of activated carbon produced from materials used in wastewater treatment. The environmental impacts (global warming potential, stratospheric ozone depletion, ionizing radiation, ozone formation human health and terrestrial ecotoxicity, terrestrial acidification, freshwater and marine eutrophication, marine eutrophication, fine particulate matter, freshwater and human carcinogenic toxicity, human non carcinogenic, land use, mineral resource scarcity, fossil resource scarcity and water consumption are quantified for coal, wood and coconut shells based activated carbon life cycles.

PERFORMANCE ASSESSMENT

For the performance assessment between coal, coconut and shell in terms of adsorption of inorganic and organic pollutants, comprehensive literature review was conducted using journal papers published between 2004 to 2022. Out of all articles, nine articles were selected for assessment. As a means of comparison of performance, adsorption capacity was used which is defined as the quantity of adsorbate molecules taken up by a particular adsorbent per unit mass of the adsorbent as shown in (Equation 1.0) from (Sizirici et al. 2021).

$$Qe = (Co - Ce) \cdot v / m \ (1) \qquad (1)$$

where, Qe = adsorption capacity (mg/g), C0 = initial concentration (mg/ L), Ce = final concentration (mg/L), V = volume of the sample (L) and m = mass of the adsorbent (g).

RESULTS AND DISCUSSION

LCIA RESULTS

OpenLCA software was used to carry out the life cycle assessment (LCA) on the waste materials for activated carbon uses in wastewater treatment, where inventories of the waste materials were input and examined. The inventories in this assessment were analysed using the ReCiPe midpoint approach. The data for the inventory came from past study all around the world literary sources. Utilising raw resources and energy inputs as well as published emissions from prior literature studies, OpenLCA software assessed the cradle-to-gate LCI of raw material and energy consumption as well as environmental output (flows) on a per-functional-unit basis based on 1 kg of AC. (Table 4) summarizes the Life Cycle Impact Assessment (LCIA) findings for each processes from raw material extraction until activated carbon process.

In thirteen of the eighteen impact categories, wood has the greatest environmental impact. Wood, in particular, has a 1-2 times larger environmental impact in each of the three most major categories reported in the normalised LCIA impacts which are ionising radiation 3.94E+00 of kBq Co-60 eq freshwater eutrophication 1.59E-01 of kg P eq, and mineral resource scarcity 4.78E-01 of kg Cu eq (Copper equivalent). This can be understood by the emissions produced by wood chipping and drying process that contribute in environmental impact along the processes of activated carbon which use 0.124 kWh source of electricity (Kim et al. 2018). The heat and gases also created during activation are used to produce wood as an activated carbon that impact in global warming (Figure 3). Significant waste can be produced during the drying and chipping of wood, such as tree bark, sawdust, or wood chips, that needs to be properly disposed of or processed further.

Coconut shells has the lowest total environmental impacts, ranking first or second in fifteen among the eighteen environmental categories. Specifically, the lowest impact category in environment of coconut is stratospheric ozone depletion which is 4.12E-05 kg CFC11 eq while the highest impact category is the land use, 1.06E+01 m2a crop eq. Massive operations cultivation of coconuts can cover vast expanses of land, resulting in a greater land use impact. Nonetheless, in other categories, their consequences are comparable to or even exceed those associated with coal and wood. In Figure 4, coconut-based activated carbon has been considered to be more environmentally beneficial than coal because coconut shells are a byproduct of coconut processing. Using a byproduct can help to lessen overall environmental effect. Past study from (Kim et al. 2018) shows that GWP from 1kg AC from wood wastes and coconut shells were 1.04E-02 kg CO2 eq and 1.15E+00 kg CO2 eq respectively while this study evaluates 1kg AC from wood wastes and coconut shells are 1.71E+01 kg CO2 eq and 7.17E+01 kg CO2 eq respectively.

Coal on the other hand, has the highest impact on environment in categories of global warming and stratospheric ozone depletion which are 7.21E+02 kg CO2 eq and 2.10E-01 kg CFC11 eq respectively. This is because to the emissions from the mining of coal and natural gas production, which are not present in the life cycles of other AC types. In contrast, past study from (Vilen et al. 2022) indicates that coal GAC had peak environmental impact in ten out of the twelve impact categories with the production methods assumed in the study. Coal mining the initial stage of the process emits methane, a powerful greenhouse gas that considerably contributes to the global warming projected by coal-fired AC. Moreover, based on (Figure 5), coal has a significant Global Warming Potential (GWP) the combustion of coal and natural gas during the carbonisation and activation stages of AC production emits significant volumes of CO2, increasing the carbon footprint.

GWP is an important indication of impact on the phenomenon of climate change. In Figure 5, all eighteen categories of environment impact have significant value in coal activated carbon production. Coal-based activated carbon may have greater environmental implications since it involves coal extraction and processing, as well as the accompanying energy consumption during carbonisation. Coal is a resource that is not renewable, and its use likely to cause more carbon emissions than renewable ones.

The findings indicate that coal AC have fewer direct carbon emissions than wood AC. Fossil-based materials contain more carbon, requiring less burn-off to achieve the high carbon concentration of AC. The GWP of coal AC remains among the greatest due to emissions from mining and gas generation which contributes overall impact. In comparison, AC that utilises coconut shells and wood has a lower global warming potential and ozone depletion impacts. Coconut shells are a waste byproduct of coconut manufacturing, therefore employing them as a raw material in AC production helps to reduce the total environmental impact. Wood, while requiring additional processing processes, is a renewable resource that can be handled efficiently.

TABLE 4. Summary of LCIA results for coal, coconut shells and wood

Indicator	Coal	Coconut	Wood	Unit
Fine particulate matter formation	1.41E-01	1.80E-02	4.47E-01	kg PM2.5 eq
Fossil resource scarcity	1.51E+01	2.49E+00	1.42E+01	kg oil eq
Freshwater ecotoxicity	2.89E-01	6.99E-01	2.07E+00	kg 1,4-DCB
Freshwater eutrophication	5.81E-03	2.25E-03	1.59E-01	kg P eq
Global warming	7.21E+02	1.71E+01	7.17E+01	kg CO2 eq
Human carcinogenic toxicity	4.97E-01	3.12E-03	3.45E+00	kg 1,4-DCB
Human non-carcinogenic toxicity	1.58E+01	1.18E+01	1.59E+02	kg 1,4-DCB
Ionizing radiation	5.49E-01	2.02E-03	3.94E+00	kBq Co-60 eq
Land use	6.01E-01	1.06E+01	4.90E+00	m2a crop eq
Marine ecotoxicity	4.66E-01	4.69E-01	2.80E+00	kg 1,4-DCB
Marine eutrophication	1.07E-01	2.50E-03	1.37E-01	kg N eq
Mineral resource scarcity	1.86E-02	3.12E-03	4.78E-01	kg Cu eq
Ozone formation, Human health	1.48E-01	3.45E-02	5.84E-01	kg NOx eq

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Ozone formation, Terrestrial ecosystems	1.50E-01	3.64E-02	5.91E-01	kg NOx eq
Stratospheric ozone depletion	2.10E-01	4.12E-05	2.55E-02	kg CFC11 eq
Terrestrial acidification	5.09E-01	6.85E-02	1.36E+00	kg SO2 eq
Terrestrial ecotoxicity	1.03E+02	2.99E+01	2.13E+02	kg 1,4-DCB
Water consumption	3.88E-01	1.38E+00	3.89E-01	m3

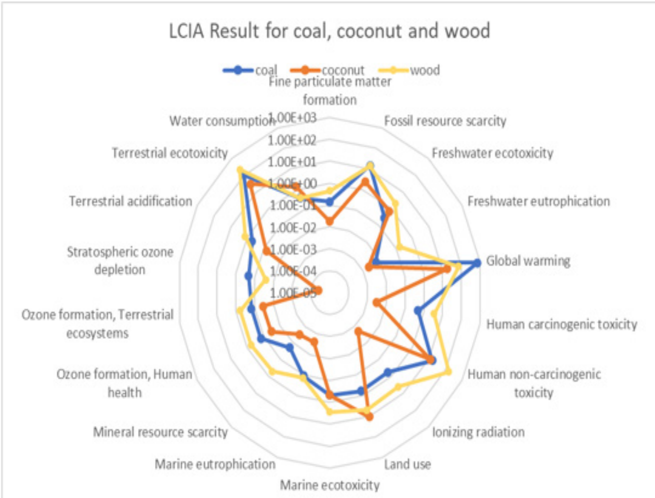

FIGURE 2. Comparison of LCIA results for coal, coconut and wood

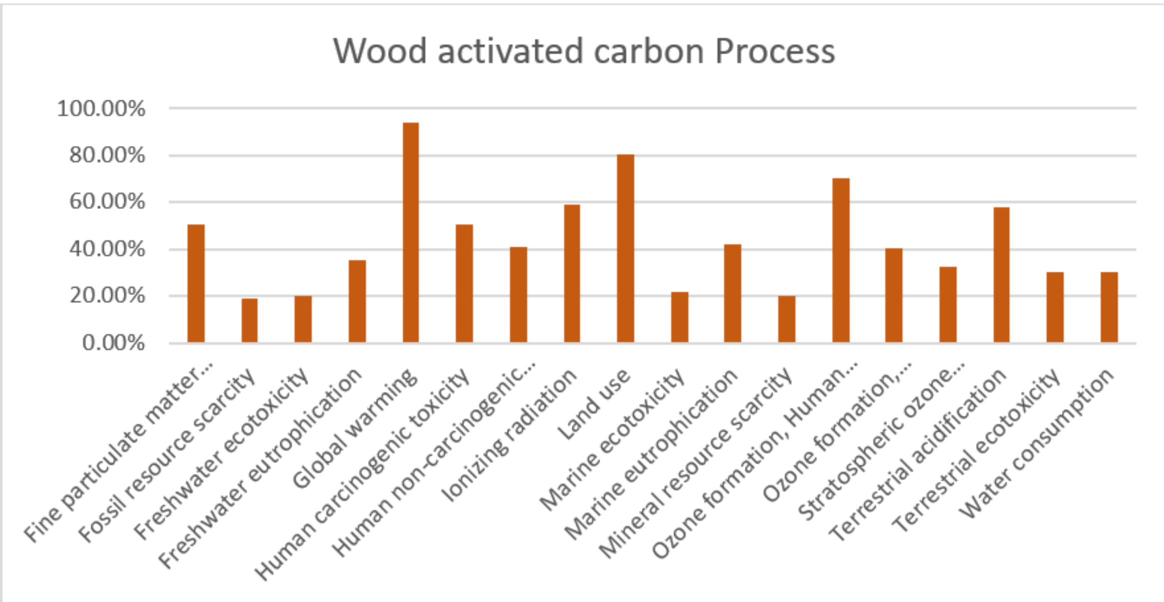

FIGURE 3. Bar graph for wood activated carbon process

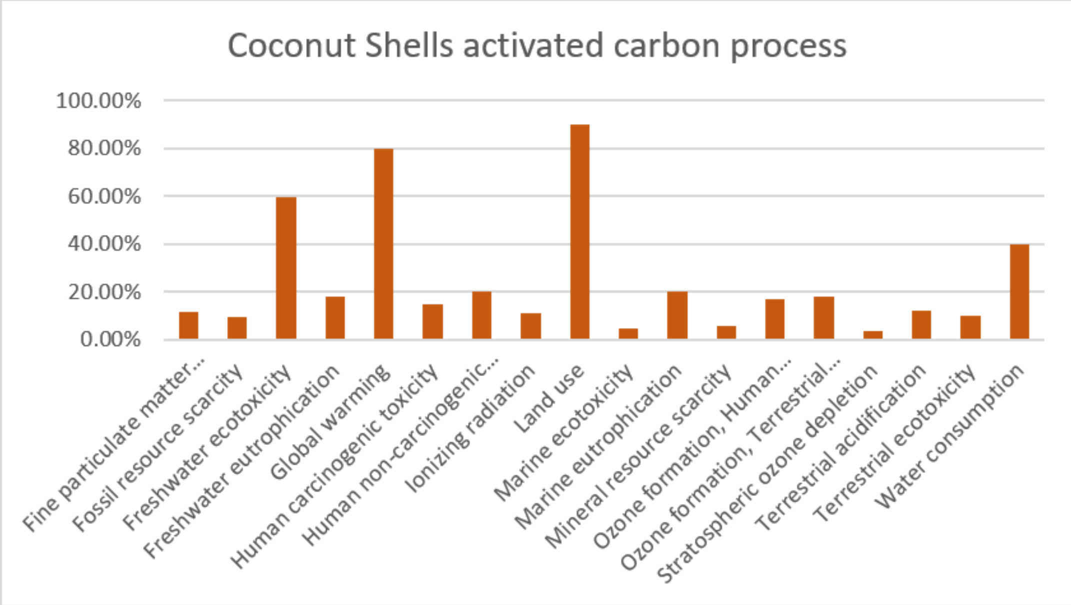

FIGURE 4. Bar graph for coconut shells activated carbon process

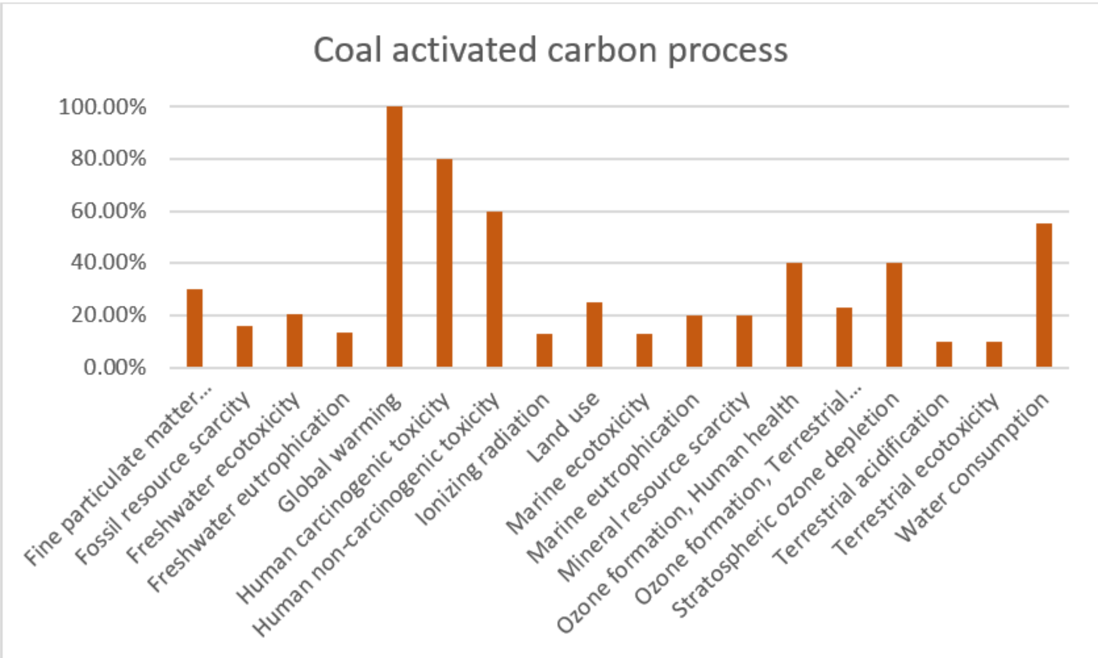

FIGURE 5. Bar graph for coal activated carbon process

SENSITIVITY ANALYSIS

The method of sensitivity analysis is used for assessing which input factors or assumption have the greatest influence on the results that are obtained. It varies important input variables such as consumption of energy and emissions components to see how they affect the total environmental impact. It allows to assess the reliability of the findings and prioritise measures for data development.

AC and power production generate the most significant environmental consequences. The sensitivity analysis focused on electricity usage and raw material requirements for producing 1 kg of AC. The computer programme tested the energy generated by solar farms for heating and electrical activities, including pyrolysis, drying, crushing, and activation of activated carbon as an adsorbent in a waste water treatment facility. In order to prepare for the frequent utilisation of open-pit carbonisation in South-East

Asia, an additional possibility was developed for wood and coconut shells. Local charcoals carbonise wood and coconut shells, which are then acquired by organisations like AC manufacture. The study attempted to determine how the effects of coconut AC vary based on production methods. The LCI for fully manufacturing coconut AC production was based on Arena et al.'s (2016) data while wood adapted from (Kim et al. 2018).

The analysis includes a scenario where industrial carbonization. of both of the activated carbon does not reduce emissions. If the scenario's data was changed to exclude the burning of methane and carbon monoxide, which would occur in open pit carbonisation processes Arena et al.'s carbon dioxide emissions were reduced accordingly assuming methane and carbon monoxide emissions.

Analysis result showed that coal contributes the most in impact on environmental which is 7.21E+02 kg CO2 eq. The sensitivity analysis indicates the activation process as a significant factor impacting GWP. Chemical activation methods using activating chemicals are examined. Chemical activation procedures may contribute to increased GWP due to their energy-intensive nature and the possibility for extra emissions. The environmental impact of manufacturing activated carbon varies greatly depending on the energy source used. It is strongly advised that cleaner energy sources be used for adsorbent manufacture to reduce environmental impact. Reducing garbage and adsorbent transportation did not significantly affect GWP levels.

The composition of electricity utilized in the manufacturing process of activated carbon significantly influences its environmental consequences. The origin of electricity, whether sourced from renewable alternatives such as solar or wind, or non-renewable sources like coal or natural gas, has consequences for emissions of greenhouse gases, air pollution, and resource depletion. Transitioning towards cleaner and sustainable energy options can notably diminish the environmental impact of activated carbon production.

Furthermore, the distances involved in transporting raw materials, intermediate products, and the final activated carbon products can affect the environmental impact of the entire supply chain. Increased transportation distances usually lead to greater energy usage, emissions, and consequent environmental effects. It's crucial to assess how transportation distances influence the overall environmental performance and pinpoint ways to enhance logistics and supply chain management to mitigate transportation-related impacts. This might involve strategies such as obtaining materials from closer locations, improving transport routes, or adopting more fuel-efficient modes of transportation. During the manufacturing of activated carbon, byproducts such as biochar or heat energy might also be generated alongside the main product. Various allocation techniques, such as mass allocation, economic allocation, or system expansion, can produce different outcomes regarding environmental effects.

THE PERFORMANCE OF COCONUT SHELLS, WOOD AND COAL AS AN ADSORBENT IN WASTEWATER TREATMENT

Wood and coconut-based products, specifically activated carbon generated from wood and coconut shells, work well as adsorbents in wastewater treatment. Both materials have large surface areas and permeability, thus being good for adsorbing a variety of pollutants. The literature comparison for adsorption capacity between coal, wood and coconut shell has been gathered in (Table 3.2). (Han et al. 2013) found that activated carbon derived from two types of wood which are softwood and hardwood could process different outcome of adsorption capacity which are 6.35 mg/g and 5.03 mg/g respectively.

Likewise, coconut-based adsorbents, especially activated carbon derived from coconut shells, exhibit superior adsorption performance. Coconut-derived materials are noted for their huge surface area, microporous structure, and presence of functional groups, which increase their affinity for different pollutants. Compared to wood AC, coconut AC shows higher adsorption capacity which is 13.7 mg/g (Mansur et al. 2021). However, study conducted by (Boopathy et al. 2013) display that the adsorption capacity for the coconut shell as an adsorbent is only 2.3 mg/g in removing ion pollutant of NH4+. Coconut-based adsorbents have been shown to effectively remove heavy metals, organic pollutants, and new contaminants from wastewater.

TABLE 5. Literature comparison for adsorption capacity between coal, wood and coconut shell

Activated Carbon (Adsorbent)	Adsorption Capacity (mg/g)	Author
Coal	1.80	(Regmi et al. 2012)
	4.10	(Chen and Wu 2004)
Softwood	6.35	(Han et al. 2013)
Hardwood	5.03	(Han et al. 2013)
Coconut Shell	2.3	(Boopathy et al. 2013)
	13.7	(Mansur et al. 2021)

On the other hand, coal forms a porous structure that may effectively absorb a variety of contaminants from wastewater, include heavy metals, organic substances, and colours once activated. Activated coal's wide area of surface and adsorption capabilities help it remove pollutants efficiently. Study conducted by (Chen and Wu, 2004) indicates that the adsorption capacity of coal activated carbon is 24.10 mg/g which is the highest adsorption compare to coconut activated carbon and wood activated carbon. Nevertheless, the negative environmental effects of coal-based adsorption, notably its potential for global warming, must be considered. The selection of the reactivation process, regenerating methods, and dose may affect either the efficiency of adsorption and the general environmental impact of coal in wastewater treatment.

Based on previous study (Table 5), the comparable percentage performance of coal, wood, and coconut shells as adsorbents was 43%, 5%, and 35%, respectively (Figure 6), reflecting various characteristics and efficiencies in their adsorption capabilities. The differences in results between studies evaluating the performance of adsorbents generated from coal, coconut, and wood can be due,

to a variety of factors, each of which influences the adsorption properties differently. For starters changes in the methods of preparation and activation processes used to create these materials can have a considerable impact on their porosity architectures and surface chemistry. Differences in activation temperatures, time, and kind of activating agent can all result in different adsorption capabilities. Coal, coconut, and wood react differentially to these activation mechanisms, resulting in variations in performance among tests.

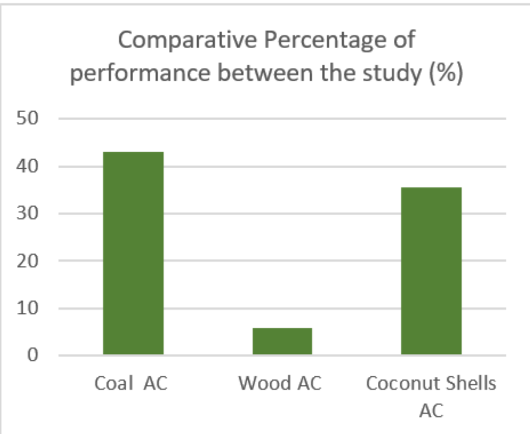

FIGURE 6. Comparative percentage graph between past studies

Additionally, the unique properties of pollutants in wastewater have a significant impact on the adsorption effectiveness of these materials. Various studies may focus on different sets of contaminants, each of which interacts differently with the adsorbent surface. Coal, coconut, and wood have varying affinity for specific pollutants, which affects overall performance. Differences in pH, temperature, and the ion concentration of the wastewater may also contribute to the disparities in results among research. Furthermore, the inherent heterogeneity in raw materials, such as coal performance, coconut shell substance, and wood different species, add to the complexity. The adsorption behaviour of these materials is influenced by variables such as particle size, surface area, and the existence of contaminants, which vary depending on the source and processing method. The precise circumstances under which these materials are procured and handled for adsorption purposes can differ between research, contributing to observed performance disparities.

CONCLUSION

This study analyses the environmental implications of AC production for several raw materials, which are coal, coconut, and wood using a single cradle-to-gate LCA. The project aims to identify raw material options for reducing the environmental impact. The life cycle assessment (LCA) of coal, coconut, and wood as activated carbon adsorbents for wastewater treatment shows that coconut shell has the lowest environmental impact of the three. Furthermore, the study advises optimising coal and wood activation methods in order to reduce their environmental impact. At the EU level, the most significant environmental consequences for all AC kinds are global warming and terrestrial ecotoxicity, as well as human toxicity. AC production's direct emissions, including activation, as well as power use, have significant environmental implications.

Further research is needed to get data on real emissions during industrial manufacturing. The cradle-to-gate study failed to take into account changes in technical efficiency during the AC's use stage, which could have influenced the comparison results. Hence, future research could consider to use cradle-to-grave method where from the extraction of raw materials being assess until recycling or disposal of the materials at the end. Additionally, future research could use life cycle estimation and assessment of environmental impact methods to evaluate the sustainability of various end-of-life solutions and guide decision-making processes. By addressing those study objectives, future studies can help to get a better knowledge of the environmental consequences of wastewater treatment procedures over their entire life cycle, ultimately promoting better and more resilient water management methods.

The correlation between LCA and the performance of adsorbents derived from waste materials is critical for determining the long-term sustainability of these materials across their life cycle. LCA provides a comprehensive structure for assessing the impact on the environment at every phase, supporting decision-making and encouraging progress towards environmentally friendly and efficient adsorption technologies for wastewater treatment. Further research is needed to determine its economic sustainability and effectiveness in diverse applications. They provide a possibility for preventing waste from entering the waste stream. In conclusion, the findings highlight the need of choosing adsorbents not solely according to their ability to absorb pollutants in water but also on their life cycle impact on the environment.

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DECLARATION OF COMPETING INTEREST

None.

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