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Portrait of Biochar Utilization from Local Biomass as a Sustainable Solution in West Sumatra, Indonesia

Refita Mayasari
Karabuk University, Demir Çelik Campus, Kastamonu Road, Kılavuzlar/Karabük

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Correspondence author:
Refita Mayasari
refitamayasari9@gmail.com

Abstract
The paper presents an extensive exploration of the utilization of biochar derived from indigenous biomass as a sustainable solution in West Sumatra, Indonesia. The region, abundant in diverse biomass resources, offers substantial prospects for the production and application of biochar. This paper aims to elucidate the accessible biomass reservoirs within the area, expound upon the biochar production process, and study its various applications in overcoming sustainability problems. A comprehensive assessment of existing literature and case studies is conducted to scrutinize the feasibility and impact of biochar application across multiple domains, notably in agriculture, waste management, and environmental conservation. Through this analysis, the study strives to uncover the potential benefits and challenges associated with integrating biochar technology into various facets of West Sumatra's landscape. Furthermore, the paper undertakes an evaluation of the environmental advantages and economic implications attributed to the adoption of biochar technology within the region. This evaluation encompasses discussions on the technology's capacity to curtail greenhouse gas emissions and enhance soil fertility, thereby contributing to the overall ecological balance and agricultural productivity. By identifying key challenges and opportunities, this study endeavors to furnish recommendations targeted at policymakers, stakeholders, and the local community. These recommendations aim to facilitate and encourage the widespread adoption of biochar as a sustainable solution in West Sumatra. Such adoption is envisioned as a pivotal step towards the preserving of the local environment while concurrently fostering socio-economic development within the region. Ultimately, the study seeks to underscore the potential transformative impact of biochar technology as a catalyst for environmental preservation and sustainable growth in West Sumatra, Indonesia.

1. Introduction

West Sumatra has great potential in biomass production, especially rice husk and palm oil waste. In 2019, rice husk production reached 370,749 tons, equivalent to 25% of the total rice production in the region. West Sumatra's advantage as a biomass producer lies in the availability of abundant biomass resources. This factor is supported by the tropical geographical conditions of Indonesia, the vast area of West Sumatra, the large population, and the rapid growth of the agricultural industry. In particular, the potential of palm oil waste is the main focus, especially in West Pasaman Regency. This region is the center of the palm oil agro-industry with an area of 154,067.18 Ha and operated by 14 palm oil companies [1].

The objectives of this paper cover three main aspects: First, to describe locally available biomass resources in the West Sumatra region; second, to provide an in-depth understanding of biochar production processes that can be implemented by utilizing these biomass resources; and third, to explore various biochar applications with the aim of addressing sustainability issues involving agriculture, waste management, and other environmental challenges. As such, this research is a first step in supporting the development of sustainable solutions in West Sumatra, opening the door for technological innovation and the adoption of practices that can address the complex issues faced by the region.

Biochar is a porous solid material that contains a lot of carbon and is produced through incomplete combustion of organic waste or biomass. The ash level in biochar is relatively low, while the carbon content is high. Biochar is stable to decomposition, alkaline, has a porous, fine texture, is able to absorb substances, and contains important nutrients, especially Phosphorus (P) and Potassium (K). In the long term, the use of biochar has an effective impact in improving soil quality [2].

One technique for biochar formation involves pyrolysis, which is the heating of organic materials or biomass without or with minimal amounts of oxygen at temperatures ranging from 250 to 700°C, as described by Ridhuan et al (2019). Pyrolysis is basically a process of decomposing materials with the application of heat in the absence of oxygen, which begins with the combustion and gasification stages, then followed by partial or total oxidation of the main products, as stated by Nurkholifah et al (2020). The result of this process is biochar, which is formed from incomplete combustion, leaving nutrients that can make a positive contribution to land fertility.The utilization of biochar from biomass sources in West Sumatra has tremendous significance in efforts to realize sustainability in this region. Biochar not only has the potential to improve soil fertility and agricultural productivity, but can also effectively reduce greenhouse gas emissions, contributing to climate change mitigation. By utilizing local biomass, biochar utilization not only creates innovative environmental solutions, but also provides opportunities for sustainable local economic development. This initiative can be a strategic pillar in driving regional economic growth while preserving West Sumatra's environment for future generations.

2. Methodology

This research uses the traditional review method to explore the utilization of biochar from local biomass as a sustainable solution in West Sumatra, Indonesia. The importance of this research is driven by the abundance of natural resources in West Sumatra, especially in agriculture, forestry, and other sectors that have the potential to become one of the pillars in the global energy arena. A comprehensive literature search was conducted from various sources such as scientific journals and reliable online sources. Inclusion and exclusion criteria were applied to select relevant literature, where the included literature should address the utilization of biochar from local biomass in the West Sumatra region or surrounding areas, as well as its impact on sustainable solutions.

The selected literature will be critically evaluated to assess the quality, relevance and strength of the evidence presented. Key information from each literature will be extracted to provide a comprehensive picture of biochar utilization from local biomass in West Sumatra as a sustainable solution. The data and information obtained will be analyzed and interpreted to answer the research questions, focusing on identifying patterns, trends and gaps in the literature related to the topic. Results and discussion will include presentations on biomass diversity as a potential renewable energy source, the potential of biomass in West Sumatra as a form of renewable energy, and biochar production technology as renewable energy in West Sumatra.

The results of the literature review will be presented in a structured narrative form, including introduction, methodology, results and discussion, as well as conclusions and recommendations. This research will provide an overview of the utilization of biochar from local biomass in West Sumatra as a sustainable solution, as well as identify the potential and challenges associated with it, so that it can contribute to the development of renewable energy in West Sumatra and Indonesia in general.

3. Results and discussions

3.1 Biomass sources in West Sumatra

West Sumatra, as one of the provinces in Indonesia, is not only an integral part of biomass production, but also stands out in its contribution especially through rice husk and palm oil waste resources. The peak rice husk production figure of 370,749 tons in 2019, equivalent to 25% of the region's total rice production, signifies West Sumatra's central role in producing biomass with great potential [1]. West Sumatra's main advantage as a biomass supplier lies in the abundance of these resources. The tropical geography of Indonesia and the size of West Sumatra contribute significantly to this abundance of biomass resources. With the addition of a large population and a rapidly growing agricultural industry, West Sumatra has great potential to become a leader in the utilization of biomass as a renewable energy source. Based on sources from D.P.K.P (2015), the potential for oil palm waste-based biomass development in West Sumatra is huge, driven by the fact that the largest plantation production in the province comes from the oil palm commodity, reaching 1,082,820 tons in 2014. The main focus of this palm oil production is centered in West Pasaman District, which is one of the leading agro-industrial plantation areas in West Sumatra. Specifically in West Pasaman District, oil palm plantations dominate as the largest commodity with an area of 154,067.18 hectares.

The existence of this agro-industrial plantation creates significant potential for biomass generation, particularly through the utilization of palm oil waste. With production reaching its peak in 2014, West Sumatra, particularly West Pasaman, has a golden opportunity to develop technologies and innovations in palm oil waste management, making a major contribution in supporting the environmental and economic sustainability of the region. By understanding the abundant biomass potential in West Sumatra, particularly from palm oil waste, strategic efforts need to be made to optimize the utilization of this resource. Thus, West Sumatra can play a role as a driving force in the development of renewable energy, providing a positive impact on the regional economy and the surrounding environment.

3.2 Biochar

Biochar is a solid substance formed through the carbonization process of biomass, often also known as "activated charcoal". Biomass that can be used as material for biochar production comes from various agricultural and forestry wastes, including rice husks, straw, coconut shells, sawn wood, tree branches, wood chips, corn cobs, sago pulp, and so on. In terms of shape, color, and manufacturing process, biochar resembles conventional wood charcoal commonly found in the market. Although biochar technology is not new, it is being reintroduced due to its vital role in the agricultural sector and the development of alternative energy sources [2].

The utilization of biochar in the agricultural sector, especially in cayenne pepper plants. The use of biochar has been shown to make a positive contribution in increasing the growth and yield of cayenne pepper plants. Another advantage is the ability of biochar to last long in the soil because it is stable and less easily decomposed. In addition, biochar can also play a role in reducing gas emissions due to its slow decomposition process. Biochar also supports cation exchange in the soil and contributes to maintaining the availability of nutrients, such as nitrogen (N), phosphorus (P) and potassium (K). Thus, the application of biochar not only provides direct benefits to plant growth, but also plays a role in supporting the sustainability of the agricultural environment [3].

3.3 Biochar production process

3.3.1 Pyrolysis

Pyrolysis, which is the process of thermal decomposition of organic matter in the absence of oxygen in the temperature range of 250-900°C, can be explained as an alternative method to convert biomass waste into value-added products such as biochar, syngas, and bio oil [4]. During the course of this process, lignocellulosic components such as cellulose, hemicellulose, and lignin undergo various reactions such as depolymerization, fragmentation, and cross-linking at certain temperatures. As a result, various types of products such as solids, liquids, and gases are formed. Solid and liquid products include charcoal and bio oil, while gaseous products include carbon dioxide, carbon monoxide, hydrogen, as well as syngas (C1-C2 hydrocarbons).

In this process, different types of reactors such as paddle kilns, bubbling fluidized beds, wagon reactors, and agitated sand rotating kilns are used to produce biochar. The outcome of this pyrolysis process, biochar, is influenced by the type and nature of the biomass used. Temperature was also identified as a key condition determining the efficiency of the product with the general trend being that biochar yield tends to decrease and syngas production increases as the temperature increases during the pyrolysis process [5]. The pyrolysis process takes place in an unreacted atmosphere where ordered matter is broken down into smaller sizes at specific temperatures and operating conditions. Pyrolysis is a very complex process where thousands of chemical reactions occur in seconds and minutes. As pyrolysis progresses, hot vapor is released from the biomass, which is then condensed into bio oil, and the remaining residue is known as biochar [6].

Pyrolysis is carried out in an unreacted atmosphere because the given temperature exceeds its thermal stability limit to obtain a more stable final product. Pyrolysis can be divided into two stages of decomposition: the primary stage and the secondary stage. In the main stage, the biomass is broken down and decomposed into its main components (such as carboxyl, carbonyl, and hydroxyl groups) by using heat. This stage involves dehydration, decarboxylation, and dehydrogenation reactions to convert the biomass into products. After the main stage is completed, the second stage begins, where the bulky compounds are broken down, and the bioplimoer is converted into charcoal or gas (such as CH_2, CH_4, CO and CO_2) [7]. A small portion of the hot vapor is converted back into bio oil, which is the aqueous phase. Catalytic cracking and thermal cracking are used to break bio polymers and can be explained by the following reaction: The first section towards the product side shows the gas yield with the converted gas formed during the process. However, the second section towards the product side displays a combination of various liquid products, and the last term is the solid yield.

3.3.2 Hydrothermal carbonization

Hydrothermal Carbonization (HTC) is a process of transforming biomass into solid hydrocarbons called hydrochar. The process involves heating biomass in an environment of highly pressurized water and high temperature, producing products in the form of solid, liquid, and gas phases. To achieve optimal efficiency in the HTC process, an in-depth understanding of process parameters such as temperature, feedstock type, reaction time, catalyst usage, and pressure is required. In this context, temperature is considered a key parameter as it provides the heat required for the disintegration and fragmentation of bonds in the biomass structure [8].

The main results of the HTC process involve the formation of gases, liquids, and solids, and the conversion efficiency of biomass tends to increase as the temperature increases. HTC has proven to be an effective and environmentally friendly method for producing solid fuels with high levels of energy density. In addition, this process has the potential to create high-quality solid fuels from biomass sources. Further research is ongoing to better understand the process parameters and optimize the operating conditions of HTC to obtain more efficient and sustainable results [9].

Biochar production procedure using Hydrothermal carbonization technology consists of three stages, including: Heating, reaction phase, and cooling.

a. The heating stage begins with heating the autoclave at maximum power until the suspension reaches a temperature of 220°C;
b. After that, only 10% of the heat power is applied in order to create sufficient time and temperature (4 hours > 180°C) for the reaction phase;
c. After the substrate has been maintained at 180°C (reaction stage) for 4 hours, the heater is turned off, and the cooling stage begins;
d. Process parameters, such as temperature, pressure, and energy consumption, are continuously observed.

3.4 Biochar application

Biochar has been the focus of intense research for researchers due to its eco-friendly nature, affordable production cost, and ease of preparation from various types of biomass using thermochemical techniques. The success of biochar in addressing various environmental issues makes it very interesting to explore [10]. Biochar plays an important role in removing contaminants and pollutants from soil and aquatic environments, and its effectiveness can be determined by the type of biomass used and its pyrolysis temperature. Biochar obtained from pyrolysis at high temperatures tends to have better efficiency in removing organic pollutants because it has properties such as porosity, surface area, suitable pH, low dissolved carbon content, and hydrophobic properties. In contrast, biochar produced from pyrolysis at low temperatures has oxygen-containing functional groups, high dissolved carbon content, and lower porosity, making it more suitable for removing inorganic pollutants. Other factors such as soil pH and biochar residence time also play a role in determining its capacity to remove pollutants. In addition, biochar also has a wide range of potential applications, such as as a catalyst, in wastewater treatment, compost, energy storage, carbon sequestration, and soil quality improvement [10].

3.4.1 Organic pollutants

Biochar has been used to remove organic pollutants from soil and water. When applied to soil, biochar adsorbs organic pollutants such as agricultural chemicals (e.g., insecticides, herbicides, pesticides), industrial chemicals (e.g., PAHs), antibiotics and pharmaceuticals, cathionic dyes, and volatile organic compounds. This removal mechanism is directly related to the interaction between biochar and pollutants, occurring through the processes of physiorption and chemosorption in the presence of various functional groups such as OH and COOH. The use of biochar has been shown to reduce the bioavailability of soil organic pollutants and uptake by plants and microbes [11].

3.4.2 Inorganic pollutants

Biochar has been found suitable for adsorbing inorganic contaminants, particularly heavy metals. Biochar produced at low temperature has many functional groups, high organic carbon content, and porosity, making it effective for inorganic pollutant removal. The dominant mechanism for the removal of inorganic pollutants, particularly heavy metals, is ion exchange, which is facilitated by the physicochemical characteristics of biochar [12].

3.4.3 Catalyst

Biochar can serve as a catalyst with applications in areas such as agriculture, environment, and energy. Its surface area and functional groups make it suitable for catalytic activities, including biodiesel production, energy production, tar removal, waste management, syngas production, and electrodes in microbial fuel cells [13].

3.4.4 Amandment soil

Biochar, when used as a soil amandment, can improve fertility, soil structure and microbial activity. It increases soil cation exchange capacity (CEC) by providing a larger surface area to adsorb cations, and can also add nutrients to the soil or serve as a nutrient source for microbial communities. In addition, biochar can increase soil pore fraction, promote microbial growth, and increase the residence time of moisture, air, and nutrients, which contribute to plant growth. Biochar produced at high temperatures is more resistant to degradation and can remain in the soil for longer periods. Furthermore, the application of biochar as soil amelioration can reduce global warming gas emissions by converting carbon released from biomass combustion into biochar through gasification or pyrolysis processes, which can then be returned to the soil [14] [15].

3.4.5 Carbon storage

Carbon storage is a promising method to reduce CO_2 emissions in soil, and biochar has been identified as a potential tool to achieve this goal. Biochar is resistant to degradation by microbes due to its aromatic structure, making it effective for carbon storage in soil. When biochar is applied to the soil, it can help minimize CO2 emissions into the atmosphere, contributing to the reduction of climate change effects. The presence of biochar in the soil can cause both positive and negative effects on carbon emissions [16] [17].

3.4.6 Wastewater treatment

Biochar has been utilized in wastewater treatment due to its ability to adsorb. Biochar has been used for adsorptive separation of toxic metals from industrial wastewater, such as electroplating wastewater, and for removal of Cu(II) ions from aqueous media. The surface area and porous nature of biochar make it effective for adsorbing contaminants from water, and its application in wastewater treatment shows potential in addressing water pollution problems. The adsorption properties of biochar make it suitable for removing various pollutants from water, including heavy metals and organic compounds. The porous structure and surface area of biochar provide sufficient sites for contaminant adsorption, making it an effective material for water treatment applications. In addition, biochar has been explored for stormwater treatment, demonstrating its potential in addressing water quality issues [10].

3.4.7 Biochar's potential for economic growth

Biochar has the potential to significantly improve economic growth and sustainability across multiple sectors. In terms of agricultural productivity, biochar can improve soil fertility and nutrient availability, resulting in increased crop yields and an overall increase in agricultural productivity. This, in turn, has a positive impact on farmers' income. In addition, the production of biochar from various biomass sources, ranging from agricultural and forest waste to organic waste from the food industry, provides an opportunity to create value from waste. This not only contributes to economic benefits but also helps reduce environmental impacts, promoting efficient waste management practices. In the realm of environmental protection, the use of biochar in agriculture and land management is emerging as a promising strategy to reduce greenhouse gas emissions. This is in line with global efforts to mitigate climate change, offering long-term economic benefits by minimizing the economic impacts associated with climate change [18].

In addition, biochar is used in water treatment, where its use in wastewater treatment can effectively remove contaminants and pollutants. This creates potential business opportunities in the wastewater treatment industry, further contributing to economic growth. Furthermore, biochar production through pyrolysis produces bio oil and bio gas, thus contributing to the development of renewable energy sources. This diversification of energy sources has potential economic benefits and is in line with ongoing efforts to shift to more sustainable and renewable energy practices [10]. In summary, biochar's versatile applications underscore its potential to drive economic growth and sustainability across a range of sectors, including agriculture, waste management, environmental protection and renewable energy.

3.5 Critical discussion on the portrait of biochar utilization from local biomass as a sustainable solution

Based on the analysis conducted by applying the traditional review method on the utilization of biochar from local biomass in West Sumatra, there are several critical aspects that need further discussion and consideration. First, the sustainable availability of biomass needs to be evaluated comprehensively, considering that the growth of the agricultural and industrial sectors can increase the demand for biomass which has the potential to cause resource depletion or environmental degradation if not managed properly. Second, technological barriers and challenges such as the availability of advanced equipment, the need for specialized skills and economic viability need to be addressed, and potential solutions explored. Third, a thorough environmental impact assessment is essential, including addressing potential negative impacts such as greenhouse gas emissions, water consumption and land use change, and appropriate mitigation strategies.

Fourth, a more detailed cost-benefit analysis is needed to understand the economic viability of biochar utilization, taking into account factors such as the costs of biomass collection, transportation, processing, and biochar application, as well as market demand and pricing strategies. Fifth, adoption and stakeholder engagement challenges such as lack of awareness, resistance to change, or conflicts of interest must be addressed through effective strategies. Finally, the scalability and replicability of the proposed solutions in other regions also need to be considered, taking into account geographical variations, biomass availability, and socio-economic conditions. By addressing these critical aspects, is expected to provide a more comprehensive and balanced perspective on the utilization of biochar from local biomass as a sustainable solution in West Sumatra, Indonesia.

4. Conclusion

This paper extensively discusses the utilization of biochar from local biomass as a sustainable solution in West Sumatra, Indonesia. In a region rich in biomass resources, biochar attracts researchers' attention due to its environmental friendliness, affordable production cost, and wide range of applications. The main objective of the paper is to describe the accessible biomass resources in the region, the biochar production process, and biochar applications in the context of sustainability. This literature review conducted a comprehensive evaluation of literature and case studies to explore the potential benefits and challenges of using biochar technology in various sectors, especially agriculture, waste management, and environmental conservation. The analysis also included an evaluation of the environmental benefits and economic implications associated with the adoption of biochar technology in West Sumatra. From the analysis, it was concluded that the potential of biochar includes the removal of organic and inorganic contaminants from soil and water, the role as a catalyst, soil quality improvement, carbon storage, and wastewater treatment. However, the benefits may depend on the type of biomass used, the pyrolysis temperature, and the specific application in various contexts.

Biochar has a significant role in enhancing economic growth and sustainability through key sectors such as agriculture, waste management, environmental protection, and renewable energy development. Increased agricultural productivity, biomass waste utilization, reduced greenhouse gas emissions, efficient wastewater treatment, and contribution to the diversification of renewable energy sources are some of the aspects that highlight the positive impacts of biochar. Although biochar offers potential transformative impacts on environmental conservation and sustainable growth in West Sumatra, key challenges and opportunities need to be identified. Therefore, this paper provides targeted recommendations for policy makers, stakeholders and local communities to facilitate the widespread adoption of biochar as a sustainable solution. This adoption is expected to be an important step towards local environmental conservation and socio-economic development in the region.

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