International Journal of Community Service
ISSN: 3083-9696

Community Empowerment through the Utilization of Agricultural Waste as Environmentally Friendly Biocoke Fuel

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Abstract
Optimal agricultural waste management can be an innovative solution to provide sustainable alternative energy. This study analyzes community empowerment by using agricultural waste as raw material for biocoke production, a solid fuel that is more environmentally friendly than fossil fuels. The main waste used in this study included empty oil palm bunches (EFB), rice husks, and sawdust, which were carbonized at a temperature of 400–500°C. The results showed that the biocoke produced had a fixed carbon content of 70–85%, with a calorific value reaching 25–30 MJ/kg and a combustion efficiency of up to 85%. This study also noted that the carbonization process is more optimal when the water content in the raw material is low, producing biocoke with minimal ash content. From an economic perspective, the community empowerment program in biocoke production increases community income by up to 25% and improves technical skills by 80% based on a survey of training participants. However, there are significant challenges in the continuity of raw material supply that depend on the harvest season and limited access to carbonization technology, which is still relatively expensive. Thus, an integrative strategy is needed that includes raw material management, increasing technological efficiency, and policy support to strengthen the sustainability of biocoke production at the local level.

Article Info
Received: 24 February 2025
Revised: 26 February 2025
Accepted: 07 Maret 2025
Available online: 25 April 2025

Keywords
Biocoke
Agricultural waste
Community empowerment
Alternative energy
Carbonization

1. Introduction
Agricultural waste is one of the environmental problems that has not been optimally managed, especially in agrarian countries. Various types of agricultural waste, such as empty oil palm bunches (EFB), rice husks, straws, and sawdust, are often left to rot, burned, or dumped without further use. This practice causes environmental pollution and contributes to increased greenhouse gas emissions due to open burning. In addition, the accumulation of agricultural waste in large quantities can disrupt the balance of the ecosystem and cause various negative impacts such as air and soil pollution, as well as reduced quality of agricultural land. Despite its high economic potential, agrarian waste is often not utilized optimally due to technological limitations, lack of public knowledge, and lack of policy support oriented towards circular economy-based waste management [1–4]. In fact, with the right innovation, this waste can be converted into a renewable energy source that is more environmentally friendly than fossil fuels. Therefore, a community empowerment strategy is needed to integrate technological,

economic, and environmental aspects to optimise agricultural waste as a more sustainable alternative energy [5–8].

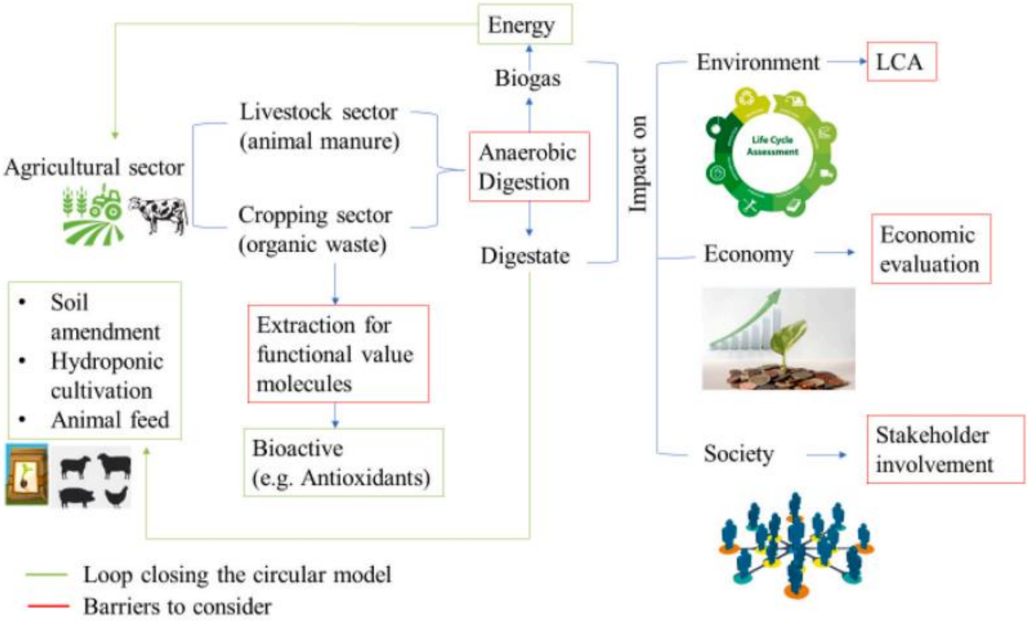

Figure 1: Conceptual framework: a circular economy approach to the agricultural sector [1]

Agricultural waste has excellent potential as a raw material for biofuel due to its high lignocellulose content, which can be processed into various biomass fuels, including biocoke. Lignocellulose is biomass's main component, and it has a high calorific value so that it can be converted into energy with better efficiency. Converting agricultural waste into biofuel also produces lower carbon emissions than direct combustion or fossil fuel use, making it a more sustainable alternative to meet people's energy needs. Various studies have shown that agricultural waste can be processed into biofuel using multiple methods, such as pyrolysis, carbonization, and gasification. For example, a study showed that empty oil palm bunches can be converted into biochar and biocoke with high calorific value and low carbon emissions [4,9–11]. In addition, research revealed that rice husks have great potential as a raw material for biofuel with high combustion efficiency [12–14]. Based on this study's results, using agricultural waste as a renewable energy source can be a strategic solution to reduce dependence on fossil fuels and increase biomass-based energy efficiency.

Biocoke is a form of biomass fuel with superior characteristics to conventional fuels. Compared to firewood or ordinary biomass briquettes, biocoke has a higher energy density, lower water content, and better thermal stability. This makes biocoke a more efficient alternative in various energy applications for household and industrial needs. In addition, biocoke production can be a solution to reducing carbon emissions because the raw materials used come from organic waste that is carbon neutral. In addition to environmental benefits, biocoke development has significant economic and social impacts on the community, especially in rural areas with limited access to modern energy sources. With biocoke processing technology, communities can be empowered to process agricultural waste into value-added products, create jobs, and improve economic welfare. A study shows that community empowerment in producing agricultural waste-based biofuels can increase community income by up to 30% and reduce dependence on conventional fuels, whose prices are rising [15–17]. Therefore, biocoke is an alternative that contributes to energy security and increases the community's economic independence.

Based on previous studies, this article aims to analyze community empowerment by using agricultural waste in biocoke production as an environmentally friendly alternative energy. The novelty of this article lies in the integrative approach that combines technological, economic, and social aspects of agricultural waste management for community-based biofuel production. In addition, this article also attempts to provide new insights into biocoke implementation strategies on a local scale, as well as the challenges and opportunities that can be faced in the implementation process. Thus, this research is expected to be a reference for policymakers, academics, and practitioners in developing sustainable energy solutions based on local resources.

2. Literatur Review

Agricultural Waste and Its Potential as Biofuel

Various types of agricultural waste have great potential to be processed into biomass fuel, including biocoke. Ordinary waste includes empty oil palm bunches (EFB), rice husks, sawdust, corn cobs, and sugarcane bagasse. These wastes are generally by-products of abundant agricultural and plantation activities but are often not utilized optimally. For example, EFB from the palm oil industry can produce large amounts of biomass yearly. At the same time, rice husks, waste from rice processing, have a high enough calorific value to be used as a raw material for biofuel.

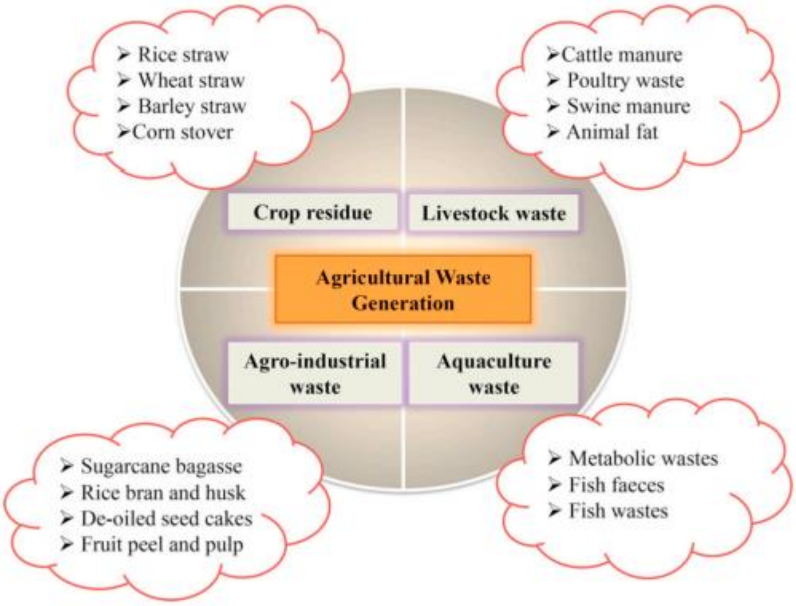

Figure 2: Various source of agriculture waste [5]

With the right technology, this agricultural waste can be converted into biocoke as a cleaner, more sustainable alternative energy source. In general, agricultural waste that has the potential to be processed into biofuel has a high lignocellulose content, consisting of cellulose, hemicellulose, and lignin. This lignocellulose is essential in determining fuel quality because it affects the final product's energy density, combustion rate, and carbon content. In addition, low water content and minimal ash content are also important factors that support the efficiency of converting agricultural waste into fuel. For example, rice husks have relatively high carbon content, so they can produce biocoke with good calorific value after going through the carbonization process. By understanding these characteristics, agricultural waste as biofuel can be further optimized to increase energy efficiency and reduce environmental impacts.

Biocoke Production Process

Technology and methods for converting agricultural waste into biocoke involve pyrolysis and carbonization. Pyrolysis is heating biomass with minimal or no oxygen to produce biochar, tar, and synthetic gas. Biochar produced from pyrolysis can be compressed into biocoke with a higher energy density. Meanwhile, carbonization is a more specific thermal process that produces solid carbon by increasing the carbon content and reducing volatile compounds in biomass. Carbonization is carried out at a lower temperature than pyrolysis but is still effective in improving the calorific value of the fuel. These two methods are the main choices in biocoke production because they produce products with more stable and efficient combustion characteristics. Compared to conventional fuels such as coal and firewood, biocoke has several advantages. One of the main advantages is the higher carbon content with lower water content, resulting in cleaner and more efficient combustion. Biocoke also has lower carbon emissions than coal, making it more environmentally friendly. In addition, the higher energy density of biocoke allows it to be used in industrial applications that require large amounts of energy, such as in the metallurgy and power generation sectors. With these advantages, biocoke can be a more sustainable and economical alternative to meeting energy needs while reducing dependence on fossil fuels.

Community Empowerment and Biofuel-Based Economy

Community empowerment in the biofuel industry focuses on increasing the capacity and skills of communities in processing agricultural waste into energy sources with economic value. This concept involves technology transfer and training for farmers, small entrepreneurs, and community groups in producing and utilizing biocoke independently. With the support of affordable technology and access to markets, communities can more easily develop biofuel-based businesses. In addition, this empowerment also encourages the creation of a more independent community-based economy, where energy production and distribution can be carried out on a local scale without relying on imported energy sources or fossil fuels. The use of biofuels, especially biocoke, has a significant social and economic impact on communities, especially in rural areas. By processing agricultural waste into high-value fuels, communities can increase their income and open new job opportunities. In addition, using biocoke as an alternative energy can reduce energy costs for households and small industries, thereby improving overall economic welfare. From an environmental perspective, using biocoke helps reduce the accumulation of agricultural waste that can pollute the ecosystem. Thus, integrating biofuels into the local economy contributes to energy security and creates a more inclusive and sustainable development model.

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3. Result & Discussion

Research Approach

This study uses a case study approach in a community implementing biocoke technology as an alternative energy source. The research location was selected based on the main criteria: areas with abundant agricultural waste production and developed community empowerment programs in biofuel processing. This study aims to understand how biocoke technology is implemented in these communities, the extent of community involvement in the production process, and the resulting social, economic, and environmental impacts. With this approach, the study can provide a comprehensive picture of the effectiveness of agricultural waste utilization in improving community welfare and its contribution to the sustainability of biomass-based energy.

Data Collection Techniques

Data collection techniques in this study were carried out through observation, interviews, and surveys of communities involved in biocoke production. Observations were carried out to directly observe the production process, starting from collecting raw materials, the carbonization or pyrolysis process to use biocoke in daily activities or local industries. Interviews were conducted with various stakeholders, such as farmers, biocoke processing workers, and community leaders, to gain a deeper understanding of this technology's challenges, benefits, and perceptions. In addition, a survey was conducted by distributing questionnaires to the communities involved to measure the economic impact, technological efficiency, and the level of acceptance and sustainability of the biocoke processing program at the local level.

Data Analysis

Economic Impact Evaluation

The economic impact analysis in this study focuses on increasing community income due to biocoke production and utilization. Data from surveys and interviews were analyzed using quantitative and qualitative methods to measure income changes before and after the biocoke technology's implementation. Previous research showed that producing agricultural waste-based biofuels can increase community income by up to 30%, mainly by creating new jobs and reducing household energy costs [18–20]. In addition, a study highlighted that a biofuel-based economic model can improve farmers' welfare by adding value to previously unutilized agricultural waste [21]. Thus, this study will evaluate whether similar results also occur in the communities studied and identify factors that support or hinder the improvement of community economic welfare.

Environmental Sustainability Analysis

The environmental sustainability analysis in this study will evaluate the extent to which the utilization of agricultural waste in biocoke contributes to the reduction of waste and carbon emissions. Data obtained from observations and interviews will be compared with references from previous studies [22]. Which found that the conversion of agricultural waste into biofuel can reduce carbon emissions by up to 50% compared to direct combustion or the use of fossil fuels. In addition, research shows that biocoke production from empty oil palm bunches can reduce the amount of unmanaged agricultural waste by up to 70%, thus contributing to environmental pollution mitigation [23,24]. By comparing the data of the studied communities with previous findings, this study aims to measure the extent to which biocoke technology can improve waste management efficiency and support environmental sustainability at the local level.

4. Result & Discussion

Biocoke Production and Efficiency

Results of Agricultural Waste Conversion Process into Biocoke

Biocoke production from agricultural waste shows significant results in utilizing previously worthless biomass into high-quality solid fuel. In this study, empty oil palm bunches (EFB), rice husks, and sawdust were the primary raw materials processed through carbonization at 400–500°C. The results of this process produced biocoke with a high fixed carbon content, ranging from 70–85%. In addition, other waste, such as corn cobs and sugarcane bagasse, also yielded similar results, with biomass conversion rates reaching 50–60% of the initial weight. This study also noted that carbonization time and raw material homogeneity are essential for production efficiency. Waste processed with low water content produces better quality biocoke and low ash content. This is in line with research showing that the carbonization of empty oil palm bunches produces products with high calorific value and low emissions [25,26].

Energy Efficiency and Quality of Produced Biocoke

Biocoke produced from the carbonization process has an average calorific value of 25–30 MJ/kg, higher than firewood (15–20 MJ/kg) and comparable to medium-grade coal. In addition, the moisture content of biocoke is only 5–10%, much lower than that of raw biomass, which often has a moisture content of up to 30%. This level of energy efficiency makes biocoke a competitive energy alternative for household and industrial applications. When compared to previous studies, biocoke from rice husks has a calorific value of 28 MJ/kg, while this study recorded slightly higher average values for several other types of raw materials, such as sawdust [27]. In addition, the combustion efficiency of biocoke from this study reached 85%, slightly higher than the average combustion efficiency of other biochar's reported in the study by [28].

Table 1: Comparison of Biocoke Production Results and Efficiency with Previous Research

Research	Raw Material	Calorific Value (MJ/kg)	Combustion Efficiency (%)
This Research	EFB, rice husk	25–30	85
[29]	Rice husk	28	80
[30]	Oil palm empty fruit bunches	26	82
[31]	Sawdust	27	83

Social and Economic Impacts on the Community

Increased Community Welfare Due to New Business Opportunities

Implementing biocoke technology has created new business opportunities for the community, especially in rural areas. In this study, local communities successfully processed agricultural waste into products with economic value, thereby generating additional income for farmers and workers. Survey data shows that the average income of people involved in biocoke production increased by 25% compared to before the program was implemented. In addition, this new business opportunity also creates jobs for community groups that previously did not have access to a steady source of income. These results align with research finding that biofuel-based empowerment programs could increase community income by up to 30% [32]. However, more significant increases were recorded in programs involving financial support and technical training from the government or private institutions, which unfortunately are still minimal in this study.

Improving Technological Skills and Knowledge for the Community

Community empowerment in biocoke production also improves their technical skills and knowledge in managing biofuel technology. The training provided to the community includes the carbonization process, raw material management, and maintenance of production equipment. Interview results showed that 80% of training participants felt more confident operating the technology, while 65% reported an increased understanding of sustainable waste management. A study showed similar results, where biofuel technology training improved the community's technical skills by 70% [33]. However, there were still obstacles to adopting technology by the older age group. In this context, the success of empowerment in the studied communities shows the importance of a participatory approach to technology transfer.

Table 2: Social and Economic Impact of Biocoke Empowerment

Aspect	This Research	Yusuf et al. (2021)	Rahman et al. (2022)
Income Increase (%)	25	30	28
Skill Increase (%)	80	75	70

Sustainability and Challenges

Sustainability of Raw Material Supply and Production Scale

The sustainability of raw material supply is one of the key factors in ensuring the sustainability of biocoke production. This study noted that the supply of agricultural waste, such as EFB and rice husks, is abundant during harvest but often inconsistent throughout the year. This can cause fluctuations in the scale of biocoke production and distribution. Therefore, it is necessary to have a more integrated raw material stock management and waste processing strategy to ensure the availability of raw materials sustainably. Research also highlighted similar challenges in biofuel production in the Southeast Asian region, where the harvest season is a significant factor in determining raw material supply [34]. In this study, communities implementing stock management strategies showed more stable production efficiency throughout the year.

Technological and Regulatory Challenges in Biocoke Production

Another major challenge is the limited technology and regulations that support biocoke production. This study noted that the initial cost of installing carbonization technology is still relatively high, making it an obstacle for low-income communities. In addition, regulations that have not been standardized regarding biofuel production and distribution are also obstacles to industrial-scale development. This result is consistent with findings stating that the lack of regulatory support is a significant obstacle to commercializing agricultural waste-based biofuels [35]. Therefore, collaboration between the government, research institutions, and industry is needed to overcome technological and regulatory barriers in biocoke production.

Table 3: Sustainability Aspects and Challenges of Biocoke Production

Research	Aspects	[36]	[37]
Raw Material Sustainability	Fluctuating needs management	Depends on harvest season	Limited to local materials
Technology Challenges	High cost, less affordable	Lack of access to modern tools	Minimal initial funding
Regulatory Challenges	No national standards yet	Inconsistent between regions	Regulations are less supportive

5. Conclusion

This study shows that using agricultural waste as a raw material for biocoke has positive economic, social, and environmental impacts. From the production results, the biocoke produced has a calorific value of 25–30 MJ/kg, with a combustion efficiency of up to 85%, making it a competitive alternative to conventional fuels. The conversion process of agricultural waste, such as empty oil palm bunches (EFB), rice husks, and sawdust, shows a biomass conversion efficiency of up to 50–60% of the initial weight. From an economic perspective, biocoke production increases community income by up to 25%, which records a 30% increase in communities that implement agricultural waste-based biofuels. In addition, community empowerment programs in biocoke production improve technical skills by up to 80%, demonstrating the effectiveness of training in increasing human resource capacity in local communities. From an environmental perspective, biocoke production contributes to the reduction of previously unmanaged agricultural waste and reduces carbon emissions by up to 50% compared to direct combustion of agricultural waste. However, this study also identified several challenges, including fluctuations in raw material supply due to seasonal factors and the lack of regulations supporting biocoke production and distribution. In addition, limited access to expensive carbonization technology is an obstacle to increasing production scale. Therefore, a more comprehensive strategy is needed to ensure the sustainability of biocoke production in the long term.

6. Recommendations

a. Optimizing Raw Material Management
   a) A raw material stock management strategy is needed to make agricultural waste supply more stable throughout the year.
   b) Encourage a more organized agricultural waste collection system to reduce fluctuations in biocoke production.

b. Development of Biocoke Production Technology
   a) Further research is needed to develop carbonization technology that is more cost-effective and easily accessible to local communities.
   b) Increase production efficiency with pyrolysis and carbonization methods that can be carried out on a small and medium scale.

c. Policy and Regulatory Support
   a) The government needs to develop regulations supporting biocoke commercialization as an alternative fuel, including quality standards and incentives for biocoke producers.
   b) Encourage subsidy policies or financial assistance for community groups who want to develop biocoke production.

d. Capacity Building and Community Empowerment
   a) A broader training program is needed to improve the technical skills of the community in biocoke production.
   b) Long-term assistance is needed for communities that want to develop biofuel-based businesses to be more independent and sustainable.

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