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SYSTEMATIC LITERATURE REVIEW: UTILIZATION OF AGRICULTURAL WASTE AS RAW MATERIAL FOR RENEWABLE ENERGY BIOBRIQUETTES

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Abstract. The global energy crisis and environmental degradation caused by fossil fuel consumption have driven the search for sustainable alternative energy sources. Agricultural waste, which is abundant and often underutilized, has significant potential as raw material for biobriquettes in renewable energy production. This Systematic Literature Review (SLR) aims to comprehensively analyze research related to the utilization of agricultural waste as biobriquette feedstock during the period 2012-2025. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method was used to screen 200 articles from Web of Science, Scopus, and Google Scholar databases, with 40 articles meeting the inclusion criteria. The review results show that agricultural wastes such as rice husks, corn cobs, bagasse, and coconut shells have competitive calorific values (3.000-7.000 cal/g) meeting solid fuel standards. Factors affecting biobriquette quality include raw material type, binder type (tapioca, molasses, clay), compaction pressure (100-1000 kg/cm²), and particle size. Indonesia, with agricultural waste production reaching 136 million tons per year, has biomass energy potential of 49.810 MW. Biobriquette development not only offers effective waste management solutions but also contributes to greenhouse gas emission reductions of up to 335.679 tons CO_2-eq per 100.000 tons of biobriquettes. This SLR identifies research gaps and provides recommendations for developing more efficient and sustainable biobriquette technology.

Keywords: biobriquette, agricultural waste, renewable energy, systematic literature review, biomass, calorific value

Abstrak. *Krisis energi global dan degradasi lingkungan akibat penggunaan bahan bakar fosil telah mendorong pencarian sumber energi alternatif yang berkelanjutan. Limbah pertanian, yang melimpah dan sering kali tidak termanfaatkan dengan optimal, memiliki potensi besar sebagai bahan baku biobriket untuk energi terbarukan. Systematic Literature Review (SLR) ini bertujuan untuk menganalisis secara komprehensif penelitian-penelitian terkait pemanfaatan limbah pertanian sebagai bahan baku biobriket selama periode 2012-2025. Metode PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) digunakan untuk menyaring 200 artikel dari database Web of Science, Scopus, dan Google Scholar, dengan 40 artikel yang memenuhi kriteria inklusi. Hasil review menunjukkan bahwa limbah pertanian seperti sekam padi, tongkol jagung, ampas tebu, dan tempurung kelapa memiliki nilai kalori yang kompetitif (3.000-7.000 kal/g) dengan standar bahan bakar padat. Faktor-faktor yang*

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mempengaruhi kualitas biobriket meliputi jenis bahan baku, jenis perekat (tapioka, molase, tanite liat), tekanan pemadatan (100-1000 kg/cm²), dan ukuran partikel. Indonesia, dengan produksi limbah pertanian mencapai 136 juta ton per tahun, memiliki potensi energi biomasa sebesar 49.810 MW. Pengembangan biobriket tidak hanya menawarkan solusi pengelolaan limbah yang efektif tetapi juga berkontribusi pada pengurangan emisi gas rumah kaca hingga 335.679 ton CO_2-eq per 100.000 ton biobriket. SLR ini mengidentifikasi gap penelitian dan memberikan rekomendasi untuk pengembangan teknologi biobriket yang lebih efisien dan berkelanjutan.

Kata kunci: *biobriket, limbah pertanian, energi terbarukan, systematic literature review, biomasa, nilai kalori*

1. Introduction

Modern civilization requires an environmentally friendly, reliable, and accessible energy supply to support economic development, industrial activities, and the growing demand for electricity and household energy [1]. However, the continued dependence on fossil fuels has created numerous global challenges, including the depletion of non-renewable energy resources, environmental degradation, greenhouse gas emissions, geopolitical instability associated with energy security, and increasing fluctuations in fuel prices [2]. The combustion of fossil fuels is recognized as one of the primary contributors to climate change and air pollution, releasing large quantities of carbon dioxide (CO_2), sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter into the atmosphere [3]. These emissions not only accelerate global warming but also contribute to various public health problems, including respiratory diseases, cardiovascular disorders, and reduced air quality [4]. Consequently, growing concerns regarding environmental sustainability, energy security, and public health have accelerated research and development efforts toward renewable, sustainable, and low-carbon energy sources capable of replacing conventional fossil fuels [5]. Biomass is a crucial component of the global renewable energy mix, utilizing biomass waste, including agricultural and forestry residues, to produce solid fuel in the form of briquettes [6].

Among the various renewable energy resources, biomass has emerged as one of the most promising alternatives due to its abundant availability, renewability, and carbon-neutral characteristics [7]. Biomass refers to organic materials originating from plants, agricultural residues, forestry by-products, livestock waste, and other biodegradable materials that can be converted into useful forms of energy through biological, thermochemical, or mechanical processes. One of the most practical biomass utilization methods is the production of solid biofuels in the form of briquettes. Biomass briquettes are manufactured by compressing carbonized or non-carbonized biomass with or without binding agents into dense, uniform fuel blocks [8]. Compared with raw biomass, briquettes possess higher bulk density, improved energy density, lower moisture content, easier storage and transportation, longer burning duration, and more stable combustion characteristics [9]. These advantages make biomass briquettes a promising substitute for traditional firewood, charcoal, coal, and other fossil-based fuels in both domestic and industrial applications [10].

Indonesia's top ten commodities produce an average of 136.22 million tons per year from the agricultural sector. Rice, corn, and palm oil are the top three agricultural products, producing 75.97, 54.98, and 15.24 million tons of dry biomass residue, respectively [11]. The potential for bioenergy conversion through densification techniques is very encouraging, especially for rice straw, rice husks, corn cobs, and corn stalks, which are staple foods grown abundantly in various regions of Indonesia. More than 50% of the energy potential in food crops can be obtained from rice straw and husks, which constitute half of the total residues of all food crops [12].

Biobriquettes are increasingly recognized as one of the most promising renewable solid fuels because they are derived from abundant biomass resources that are renewable, widely available, relatively inexpensive, and environmentally friendly [13]. Unlike fossil fuels, biomass briquettes are generally considered carbon-neutral because the carbon dioxide released during combustion is approximately balanced by the carbon dioxide absorbed by plants during photosynthesis throughout their growth cycle [14]. Biobriquettes are used both in urban and rural areas for domestic (cooking, baking) and industrial purposes [15]. Their versatility and affordability make them particularly attractive for developing countries where access to clean and affordable energy remains limited. Moreover, the production of biomass briquettes contributes to circular economy principles by converting agricultural waste into value-added products, reducing landfill waste, minimizing open burning practices, creating employment opportunities in rural communities, and supporting sustainable agricultural development [16].

Despite their considerable potential, several technical, economic, and environmental challenges remain in the large-scale commercialization of agricultural waste biobriquettes. The quality and performance of briquettes are influenced by numerous factors, including the type of biomass feedstock, carbonization conditions, moisture content, particle size, binder type and concentration, compaction pressure, and storage conditions [17]. Variations in these parameters significantly affect important fuel properties such as calorific value, density, compressive strength, ignition time, burning rate, volatile matter, fixed carbon content, ash content, and emission characteristics. In addition, issues related to feedstock availability, production costs, technology adoption, quality standardization, market acceptance, and government policy continue to influence the successful implementation of biomass briquette technology in many developing countries, including Indonesia [18].

Based on the background above, the problem formulations in this systematic literature review are: (1) What types of agricultural waste have the potential to be used as raw materials for biobriquettes?; (2) What are the characteristics and quality of biobriquettes from various types of agricultural waste?; (3) What factors influence the quality of biobriquettes from agricultural waste?; (4) What are the environmental impacts of utilizing agricultural waste as biobriquettes?; and (5) What are the challenges and opportunities for developing biobriquettes from agricultural waste in the future?

This systematic literature review aims to: (1) Identify and classify the types of agricultural waste that can be used as raw materials for biobriquettes, (2) Analyze the physical and chemical characteristics of biobriquettes from various types of agricultural waste, (3) Evaluate the factors that influence the quality of biobriquettes, (4) Assess the environmental impact of utilizing agricultural waste as biobriquettes and, (5) Identify challenges, opportunities, and future research directions in the development of biobriquettes from agricultural waste.

2. Research Methods

2.1 Data

This study used the Systematic Literature Review (SLR) method, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. SLR is a systematic approach to identifying, evaluating, and synthesizing evidence from studies relevant to a specific topic [19]. This method was chosen because it can provide a comprehensive overview of the state of the art in agricultural waste biobriquette research and identify existing research gaps.

2.2 Method

Literature searches were conducted on the electronic databases Web of Science, Scopus, Google Scholar, and ScienceDirect with a publication period of 2012-2025. The keywords used included: "biobriquette", "agricultural waste", "rice husk", "corn cob", "biomass briquette", "renewable energy", "calorific value", and "densification". A combination of Boolean operators (AND, OR) was used to broaden and narrow the search results. Inclusion criteria: (1) Peer-reviewed articles published in scientific journals, (2) Articles in English or Indonesian, (3) Focus on biobriquettes from agricultural waste, (4) Presenting data on biobriquette characteristics (calorific value, water content, ash content, etc.); (5) Publications from the period 2012-2025. Exclusion criteria: (1) Conference articles, theses, and grey literature; (2) Review articles without primary data; (3) Articles without full-text available; (4) Duplicate articles; (5) Articles irrelevant to the research topic.

Table 1. Article Selection Process Based on the PRISMA Protocol

Level	Description	Number of Articles
Identification	Initial search results from the database	200
Screening	After elimination of duplicates and screening of titles/abstracts	120
Eligibility	After full-text assessment	80
Inclusion	Final article analyzed	40

Source: Data processed by the author (2025)

The selection process followed the PRISMA protocol. During the identification stage, 200 records were retrieved, consisting of 142 original research articles, 28 review articles, 18 conference papers, and 12 other publications (book chapters, theses, and reports). After removing duplicates and screening titles and abstracts, 120 records remained for further evaluation. Following full-text assessment (eligibility stage), 80 original research articles met the inclusion criteria. Finally, after methodological quality assessment, 40 peer-reviewed original research articles were included in this systematic literature review. The extracted data included: author, year, research location, type of agricultural waste, biobriquette manufacturing method, biobriquette characteristics (calorific value, water content, ash content, fixed carbon), adhesive type, and main findings.

3. Results and Discussion

3.1 Potential of Agricultural Waste as Raw Material for Biobriquettes

Agricultural waste is one of the most abundant renewable biomass resources and has significant potential as a raw material for biobriquette production. Large quantities of agricultural residues are generated annually from farming and agro-industrial activities, yet much of this biomass remains underutilized or is disposed of through open burning and landfilling. These practices not only contribute to environmental pollution but also waste valuable biomass resources that could be converted into renewable energy. Therefore, utilizing agricultural waste for biobriquette production offers a sustainable solution to both waste management and energy supply [20].

Based on the reviewed literature, agricultural waste suitable for biobriquette production can be classified into two main categories: crop residues and processing residues. Crop residues are materials left in the field after harvesting, including rice straw, corn stalks, wheat straw, sorghum stalks, cassava stems, and cocoa pods. Processing residues are generated during post-harvest or industrial processing and include rice husks, corn cobs, coconut shells and fibers, sugarcane bagasse, oilseed meal, and empty oil palm fruit bunches [21]. These lignocellulosic materials contain cellulose, hemicellulose, and lignin, which contribute to their suitability as solid biofuel feedstocks.

Indonesia has enormous biomass potential due to its strong agricultural sector. In 2021, the country's major agricultural commodities included rice (55.42 million tons), palm oil (46.22 million tons), corn (23.04 million tons), cassava (15.73 million tons), and sugarcane (2.42 million tons) [22]. The production of these commodities also generates substantial amounts of agricultural residues each year. However, farmers generally obtain economic value only from the main products, while the remaining biomass is often discarded, burned, or left to decompose. As a result, valuable biomass resources remain underutilized and may contribute to environmental pollution.

Among the available agricultural residues, rice husks and corn residues are considered the most promising feedstocks for biobriquette production because of their abundance and widespread availability. Indonesia produces approximately 21 million tons of rice husks annually, but only a small proportion is utilized for energy applications. Converting rice husks into biobriquettes increases their economic value while reducing waste disposal problems. Likewise, corn cultivation generates large quantities of cobs and stalks that are generally treated as agricultural waste despite their considerable biomass potential. These residues possess favorable characteristics for densification into solid fuel and can serve as alternative energy sources for household and small-scale industrial applications [23].

Table 2. Potential of Main Agricultural Waste in Indonesia as Raw Material for Biobriquettes

Types of Waste	Production (million tons/year)	Calorie Value (cal/g)	Energy Potential
Rice Husk	21.0	3.221 - 4.886	High
Corn Cob	5.8	4.239 - 6.386	High
Rice Straw	75.9	2.800 - 3.500	Very high
Sugarcane Bagasse	10.5	3.500 - 4.200	High
Coconut Shell	3.2	4.966 - 6.494	High
Empty Palm Bunches	15.2	3.800 - 4.500	Very high

Source: Compilation from various sources [11].

Rice husks are an abundant biomass waste, amounting to 21 million tons per year in Indonesia, but unfortunately, they have not been optimally utilized. By converting them into biobriquettes, the value of rice husks can be significantly increased. Similarly, assuming that 1 kg of dry grain contains 300 grams of husks, while 1 kg of corn produces 5 kg of cobs and stalks, it shows that biomass from rice husks and corn cobs has great potential as raw material for biobriquettes [24]. Estimated biomass production in

Indonesia reaches around 200 million tons per year, which theoretically can produce 49.810 MW, but currently only 302.4 MW is realized [25].

3.2 Characteristics of Biobriquettes from Agricultural Waste

The quality of biobriquettes is determined by several key parameters stipulated in the Indonesian National Standard (SNI 01-6235-2000), including: moisture content (≤8%), ash content (≤8%), volatile matter content (≤15%), bound carbon (≥77%), and calorific value (≥5.000 cal/g). Based on the review results, biobriquettes made from agricultural waste exhibit varying characteristics depending on the type of raw material and the manufacturing process.

Research by Rashif et al [9] showed that corn cob briquettes without polypropylene had a moisture content of 11.16%, ash content of 20.04%, bound carbon content of 77.44%, and a calorific value of 5.156.93 calories per gram. [26] reported that briquettes from a mixture of corn cob biochar and rice husk produced a moisture content of ≤5%, volatile matter content of ≤10%, a calorific value of ≤6.553 cal/g, and a combustion rate of 0.17 grams/minute which met SNI 01-6235-2000.

Table 3. Comparison of Biobriquette Characteristics from Various Agricultural Wastes

Raw material	Water Rate (%)	Ash Content (%)	Fixed Carbon (%)	Calorie Value (cal/g)	Reference
Corn Cob	11.16	20.04	77.44	5.156.93	[9]
Rice Husk + Coconut Shell	8.52	20.16	47.92	4.886	[7]
Corn Cobs + Rice Husks	≤5.0	8-10	62,62	6.553	[15]
Corn Stalk + Coconut Shell	2.20	3.22	85.5	7.339	[20]
SNI 01-6235-2000	≤8	≤8	≥77	≥5.000	[26]

The highest calorific value was obtained from a biobriquette mixed with corn stalks and coconut shells with a value of 7.339 cal/g at the optimal composition [27]. Biobriquettes with 75% corn cobs and 25% rice husks provided a calorific value of 5.331.95 kcal/kg, while carbonized corn cobs with 6% adhesive produced a calorific value of 5.516.85 kcal/kg [28]. These results indicate that mixing various types of agricultural waste can optimize the characteristics of biobriquettes.

3.3 Factors Affecting the Quality of Biobriquettes

3.3.1 Type and Concentration of Adhesive

Adhesives are a crucial component in biobriquette production because charcoal lacks plasticity, requiring a binder to maintain the briquettes' integrity during transportation, shaping, and storage. Each charcoal particle is coated with adhesive to enhance adhesion and produce uniform briquettes [5]. Adhesives can be classified into organic adhesives (starch, molasses, wood tar, gum arabic) and inorganic adhesives (clay, bentonite, cement, sodium silicate).

Starch is the most commonly used adhesive, although it is relatively expensive. Generally, about 4-8% starch is needed to make briquettes. Starch sources can be corn starch, wheat starch, corn flour, wheat flour, rice flour, tapioca starch, or potato starch [29]. Other research found that tapioca starch produces briquettes with better physical properties and calorific value than clay adhesives when making briquettes from rice husks and coffee husks [24].

Tapioca starch is an excellent choice as a binder in the production of charcoal briquettes. Compared to corn starch, briquettes made with tapioca starch exhibit lower ash content, which is crucial because excess ash can hinder the combustion process. The higher binder content results in lower ash content in the briquettes, thus ensuring a consistent combustion rate without the need for frequent ash remova [30]. The other study shows that optimum conditions are obtained by using 15% egg white binder, resulting in a moisture content of 8%, ash content of 7%, volatile matter content of 1.5%, bound carbon of 83.5%, a calorific value of 4.194.03 cal/g, and a combustion rate of 0.140 g/min [31].

3.3.2 Compaction Pressure

Compaction pressure is a crucial factor in the briquetting process, affecting the density and strength of the briquettes. High-pressure briquetting typically utilizes a heating device and is performed on materials with inherent adhesives (lignin), thus eliminating the need for external adhesives. Medium-pressure briquetting may or may not require adhesives depending on the raw material, while low-pressure briquetting machines always require adhesives [32].

The compression pressure in a mechanical piston machine is in the range of 110-140 MPa. The combination of this pressure and the heat generated from friction against the mold walls raises the material temperature to a level where the lignin content of the biomass begins to melt, acting as a binder in the process to produce stable briquettes [33]. Research shows that the higher the compaction pressure, the lower the porosity index and the higher the bulk density. An increase in pellet burning time is observed with increasing bulk density.

3.3.3 Particle Size and Water Content

Based on the review results, the granulometry of the raw material, followed by pressure, initial moisture content, compaction time, and adhesive are the most frequently used process variables in briquette production [34]. The optimal particle size generally ranges from 150-425 µm (80-100 mesh). Research shows that smaller particle sizes produce briquettes with higher density and strength.

Table 4. Types of Adhesives and Their Effect on Biobriquette Quality

Types of Adhesives	Advantages	Disadvantages	Optimal Concentration
Tapioca Party	Low ash content, environmentally friendly, readily available	High water content, not waterproof	4-8%
Corn Starch	High density, high strength	Relatively expensive, higher ash	4-7%
Molasses	Cheap, easy to get, biodegradable	Hygroscopic, sticky	5-10%
Clay	Very cheap, widely available	Increase ash content	10-15%
Egg whites	High gel strength, natural	Expensive, limited availability	12-15%

Source: Compilation of [5] & [24].

High moisture content can reduce calorific value and combustion efficiency. A low moisture content indicates that the briquettes still have sufficient pores to absorb water. This high moisture content is due to the relatively large number of pores that can absorb water [35]. The optimum moisture content for raw materials before briquetting generally ranges from 10-15%.

3.4 Environmental Impact of Biobriquette Utilization

The utilization of agricultural waste as biobriquettes provides significant environmental benefits by converting biomass residues into renewable energy while reducing dependence on fossil fuels. Developing bioenergy from agricultural residues can provide clean, affordable, and sustainable energy, particularly for rural communities where access to conventional energy sources is often limited [7]. In addition to improving energy security, the use of agricultural waste for biobriquette production helps reduce the environmental and economic risks associated with fossil fuel consumption, including greenhouse gas (GHG) emissions, air pollution, and fluctuations in fuel prices [36].

The combustion of fossil fuels releases large amounts of carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter, all of which contribute to climate change and deteriorating air quality [37]. In contrast, biomass is generally regarded as a carbon-neutral energy source because the carbon dioxide released during combustion is largely offset by the carbon absorbed by plants during their growth through photosynthesis [38]. Furthermore, utilizing agricultural residues as biobriquettes reduces the common practice of open-field burning, which is a major source of smoke, particulate emissions, and greenhouse gases in many agricultural regions.

Research by other study showed that the use of 100.000 tons of biomass briquette fuel by a heating company resulted in a significant reduction of 335.679 tons of CO_2-eq, equivalent to 91.305 tons of carbon [11]. This substitution also replaced 63.558 tons of coal, resulting in a reduction of 5.460 tons of SO_2 and 1.012 tons of PM10. Sensitivity analysis identified that transportation distance, energy consumption, and pollutant removal technology were the main factors influencing carbon reduction.

Table 5. Comparison of Environmental Impacts of Biobriquettes vs. Fossil Fuels

Parameter	Biobriquettes (per 100,000 tons)	Coal (per 100,000 tons)	Difference
CO_2-eq emissions (tons)	Low (carbon neutral)	335.679	-
SO_2 emissions (tons)	Minimal	5.460	-
PM10 emissions (tons)	Minimal	1.012	-
Resource	Renewable	Non-renewable	+
Impact of Deforestation	Low	Indirect (mining)	+

Source: Adapted from [40].

Life Cycle Assessment (LCA) LCA studies have demonstrated that the environmental performance of biobriquettes depends on the type of biomass feedstock and the production process employed. For example, [18] reported that corncob briquettes exhibited lower environmental impacts than burnt rice husk briquettes, with an eco-cost equivalent of US$0.387. These findings suggest that selecting appropriate biomass feedstocks and optimizing production processes can further improve the environmental sustainability of biobriquette technology [39]. Overall, the reviewed literature indicates that agricultural waste-based biobriquettes have considerable potential to reduce greenhouse gas emissions, promote sustainable waste management, and support the transition toward cleaner and more sustainable energy systems [26].

3.5 Briquetting Production Process and Technology

The process of densifying raw materials into briquettes is one pathway for converting biomass into energy. This method provides uniformity in solid fuel, improves physical and energy properties, facilitates storage and transportation, and provides more homogeneous combustion [30]. Briquetting technologies can be categorized based on scale and compaction method, including piston presses, screw presses, and roller presses.

Biomass densification using a roller press works on the principle of pressure and agglomeration, where pressure is applied between two counter-rotating rollers [41]. When the milled biomass is forced through the gap between the rollers, it is pressed into a mold or small pouch, forming a densified product. Roller presses are considered the world's standard technology for producing ovoid (pillow) charcoal briquettes from various biomass types [28].

The biobriquette production process generally includes several stages: (1) Collection and preparation of raw materials - agricultural waste is collected and dried to an optimal moisture content (10-15%); (2) Carbonization - raw materials are burned under oxygen-limited conditions at a temperature of 250-500°C to produce charcoal; (3) Refining - charcoal is ground to a particle size of 80-150 mesh; (4) Mixing - charcoal is mixed with adhesive (4-15%); (5) Molding - the mixture is molded using a press machine with a pressure of 100-1000 kg/cm^2; (6) Drying - briquettes are dried to a moisture content of ≤8%; and (7) Packaging - briquettes are packaged for storage and distribution.

3.6 Challenges and Opportunities for Biobriquette Development

3.6.1 Challenges

Despite the enormous potential of agricultural waste as a raw material for biobriquettes, several challenges need to be addressed. First, logistical issues related to the collection, transportation, and storage of agricultural waste, which is scattered across various locations. Second, the need for pretreatment, such as drying and size reduction, requires additional energy and costs. Third, the variability in raw material characteristics can affect the consistency of biobriquette quality [12].

Other challenges include: (1) Lack of infrastructure and processing facilities in rural areas, (2) Limited access to modern technology and capital, (3) Lack of public awareness about the potential and benefits of biobriquettes, (4) Competition with other uses of agricultural waste such as animal feed and organic fertilizer, and (5) Regulations and quality standards that do not fully support the development of the biobriquette industry [25].

3.6.2 Opportunities

On the other hand, there are various opportunities for developing biobriquettes from agricultural waste. First, increasing global awareness of climate change and the need for renewable energy is opening up a large market for biobriquettes. Second, government policy support through renewable energy and waste management programs. Third, the potential for a circular economy that integrates waste management with energy production and creates added value for farmers [32].

Other opportunities include: (1) Development of more efficient and cost-effective briquetting technology, (2) Innovation in the use of environmentally friendly natural adhesives, (3) Integration with sustainable agricultural systems, (4) Job creation in the green energy sector, and (5) Contribution to the achievement of the Sustainable

Development Goals (SDGs), especially SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

3.7 Research Gaps and Future Research Directions

Based on the review results, several research gaps were identified that need further exploration: 1. Optimization of biomass mixtures. Further research is needed to determine the optimal combination of different agricultural residues to improve briquette quality, including calorific value, density, mechanical strength, and combustion performance. 2. Development of environmentally friendly binders. More studies should focus on identifying natural, low-cost, and locally available binders that can enhance briquette durability while reducing production costs. 3. Techno-economic feasibility. Comprehensive economic analyses at the industrial scale are required to evaluate production costs, market competitiveness, investment requirements, and the commercial viability of biobriquette production. 4. Supply chain and logistics. Future studies should investigate efficient systems for biomass collection, transportation, and storage to ensure a continuous and cost-effective supply of raw materials. 5. Environmental assessment through Life Cycle Assessment (LCA). More comprehensive LCA studies are needed to compare the environmental performance of biobriquettes produced from different agricultural residues. 6. Quality standardization and certification. The development of standardized quality criteria and certification systems is essential to ensure product consistency, improve consumer confidence, and facilitate wider market adoption. 7. Integration of digital technologies. Future research should explore the use of digital technologies, such as sensors, automation, and Internet of Things (IoT)-based monitoring systems, to improve production efficiency and quality control.

4. Conclusion

This Systematic Literature Review comprehensively analyzed 40 research articles related to the use of agricultural waste as raw material for renewable energy biobriquettes. The review results indicate that agricultural waste such as rice husks, corn cobs, bagasse, coconut shells, and empty oil palm bunches have significant potential as raw materials for biobriquettes with competitive calorific value (3.000-7.339 cal/g). Factors affecting the quality of biobriquettes include the type of raw material, the type and concentration of adhesive (optimally 4-15%), the compaction pressure (100-1000 kg/cm^2), and the particle size (80-150 mesh). Tapioca starch is the most commonly used adhesive because it produces biobriquettes with low ash content and is environmentally friendly. Indonesia, with agricultural waste production reaching 136 million tons per year, has a biomass energy potential of 49.810 MW, but only 302.4 MW has been realized.

From an environmental perspective, biobriquettes offer a sustainable solution with the potential to reduce CO_2-eq emissions by up to 335.679 tons per 100.000 tons of biobriquettes used. Biobriquette development not only provides an effective waste management solution but also contributes to achieving national renewable energy targets and reducing greenhouse gas emissions. Key challenges in biobriquette development include logistical issues, the need for pretreatment, raw material variability, and a lack of infrastructure. However, significant opportunities exist through support for renewable energy policies, the potential of a circular economy, and growing global awareness of climate change. Future research should focus on formulation optimization, the development of natural binders, economic feasibility studies, and the integration of digital technology into biobriquette production.

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