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IMPACT OF CIRCULAR AGRICULTURE IN BANGLADESH: WASTE-TO-VALUE STRATEGIES FOR BIOGAS PRODUCTION AND CROP RESIDUE MANAGEMENT

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Abstract: Circular agriculture (CA), derived from circular economy (CE) principles, promotes resource-efficient, closed-loop systems where organic waste is converted into renewable energy, fertilisers, and soil amendments. In Bangladesh, poor management of livestock manure, crop residues, and urban organic waste contributes to greenhouse gas emissions, soil degradation, and environmental pollution, underscoring the need for sustainable waste-to-value strategies. This review evaluates the potential of circular agriculture in Bangladesh, focusing on crop residue management and biogas production as key pathways for resource recovery and renewable energy generation. A structured literature review of 102 peer-reviewed articles and policy documents was conducted to assess current practises, technological opportunities, and policy frameworks. Waste-to-value approaches, including composting, vermicomposting, biofertilisers, biochar, and anaerobic digestion, enable conversion of agricultural residues into nutrient-rich soil amendments and renewable energy, improving soil fertility, enhancing crop productivity, and reducing reliance on chemical fertilisers. Bangladesh generates over 106 million tonnes of biomass annually, with the potential to produce more than 5 billion m^3 of biogas. However, most biogas systems remain small-scale due to technological, financial, and awareness constraints. Expanding circular agriculture through integrated management of livestock manure, crop residues, and organic waste could reduce emissions, improve soil health, and strengthen rural energy security. Enhancing capacity building, technology transfer, green financing, and public–private collaboration is essential to scale up circular agriculture and support sustainable agricultural and energy systems in Bangladesh.

Key words: waste-to-value, crop residue management, biogas production, sustainable agriculture.

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Introduction

The circular economy (CE) is a sustainability-focused framework that emphasises minimising waste and optimising resource use, in contrast to the traditional linear "take–use–dispose" production model. In agriculture, the application of CE principles can transform conventional production systems into regenerative, closed-loop cycles that reduce external inputs, enhance biodiversity, and strengthen the resilience of food systems (Katunar, 2025). Integrating CE in agriculture is also recognised as an important pathway toward achieving several Sustainable Development Goals (SDGs), particularly those related to climate action, food security, and environmental conservation. Circular agriculture (CA) represents a resource management approach derived from CE principles that focuses on reusing agricultural waste as valuable inputs, thereby creating closed-loop production systems that minimise resource extraction and environmental impact (Azizuddin et al., 2021). Unlike the linear economic model, which follows a one-way flow of input–production–consumption–disposal (Aznar-Sánchez et al., 2020), CA seeks to optimise resource efficiency while supporting environmental, economic, and social sustainability. The fundamental concepts of CA are grounded in the principles of reduce, reuse, and recycle (Manickam and Duraisamy, 2019). Several key principles guide the implementation of circular agriculture. First, resource efficiency and system optimisation aim to reduce unnecessary consumption and minimise waste generation (Zabaniotou et al., 2015). Second, closed-loop processes convert agricultural byproducts into useful resources, such as transforming crop residues and livestock manure into organic fertilisers or renewable energy, thereby reducing dependence on external inputs and lowering greenhouse gas emissions (Stillitano et al., 2021; Ellen MacArthur Foundation, 2019). Third, regenerative technologies support nutrient cycling, restore soil health, and enhance ecosystem resilience (Morseletto, 2020). In addition, circular economy principles promote broader societal benefits, including environmental protection, economic development, job creation, and poverty alleviation (Constant et al., 2013; Ghisellini et al., 2016). These principles include designing systems without waste or pollution to avoid environmental degradation (Aznar-Sánchez et al., 2019), maximising the reuse of products and materials throughout the agro-food supply chain (Ellen MacArthur Foundation, 2019), and regenerating natural systems through the use of renewable resources that enhance soil fertility, conserve biodiversity, and maintain ecosystem functions (Velasco-Muñoz et al., 2021). Figure 1 illustrates a schematic representation of the circular economy, demonstrating how these interconnected principles can contribute to the development of sustainable agricultural systems. By adopting CA models, agriculture can function as a key driver of economic growth while simultaneously supporting biodiversity conservation, environmental sustainability, food security, and improved rural livelihoods (Bos and Broeze, 2020; Kristensen et al., 2016). In Bangladesh, the livestock sector plays a crucial role in ensuring food security and sustaining rural livelihoods. It contributes approximately 1.85% to the national GDP and supports millions of farming households across the country (BBS, 2022; DLS, 2023). The sector also generates a significant amount of organic waste, with an estimated 12.3 million tonnes of cattle manure produced annually (Rahman et al., 2017).

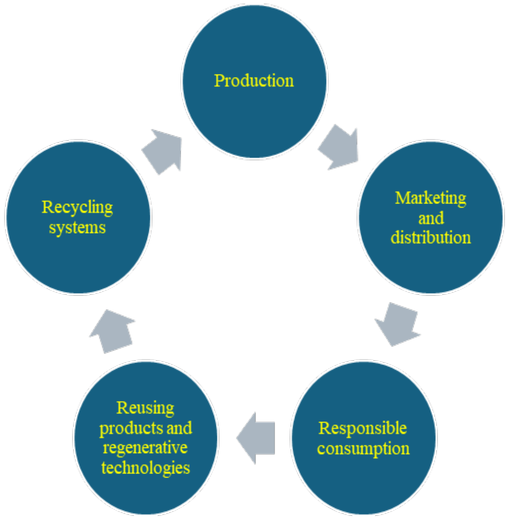

Figure 1. Schematic diagram of the circular economy.
Source: Adapted and organised by the authors from the literature.

However, conventional waste disposal practices, such as open dumping or burning, lead to the release of greenhouse gases and cause substantial environmental pollution (Gupta et al., 2016; Mudway et al., 2005; Cathy, 2023; Wang et al., 2022). Similarly, crop residues are often burned in agricultural fields, contributing to air pollution, nutrient loss, and soil degradation. These challenges highlight the urgent need for integrated waste-to-value strategies capable of converting livestock manure and crop residues into renewable energy sources, such as biogas, as well as organic fertilisers. Despite the abundance of biomass resources, the adoption of composting and large-scale biogas production systems in Bangladesh remains limited due to infrastructural, financial, technological, and policy constraints. Therefore, promoting circular agricultural practices is essential to improve waste management, reduce environmental impacts, and enhance sustainable agricultural productivity. This review focuses on waste-to-value strategies within Bangladesh's agricultural sector, with particular emphasis on biogas production from livestock manure and sustainable crop residue management. It aims to examine current practices, explore technological opportunities, and evaluate policy frameworks that can facilitate the transition toward circular agriculture, ultimately contributing to sustainable development and food security.

Material and Methods

This review explores the potential of circular agriculture to promote sustainable agricultural development and economic growth while identifying factors that contribute to institutional capacity-building. The study followed a structured literature review approach as proposed by Colicchia and Strozzi (2012) and Ammar et al. (2022). This method enhances scientific rigour, minimises bias, and facilitates the identification of emerging knowledge (Tricco et al., 2018; Mallett et al., 2012). Both quantitative and qualitative studies were reviewed using a mixed-method analysis approach (Van der Knaap et al., 2008; Mallett et al., 2012). Scholarly articles published in peer-reviewed journals were considered. Documents published in exclusively English were included to ensure global accessibility and consistency (López-Fernández et al., 2016). Duplicate and unreliable grey literature was excluded. The literature search covered the period 2000–2025, allowing the review to capture both early developments and recent advancements in circular agriculture and agricultural waste management. Searches were conducted in ScienceDirect, Web of Science, Scopus, Google Scholar, ResearchGate, FAO Library, JSTOR, and PubMed Central (Baier-Fuentes et al., 2019) using keywords such as circular economy, green economy, agricultural waste management, crop residue recycling, waste-to-value, renewable energy, and circular agriculture policy frameworks. A total of 325 studies were initially identified; after screening titles and abstracts and removing duplicates, 162 papers were shortlisted. Finally, 102 studies meeting the inclusion criteria were selected for full review. The selected literature was subjected to thematic analysis, with the studies systematically reviewed and categorised into key themes related to circular agriculture. These themes included waste-to-value strategies, technological innovations, policy frameworks, and environmental and socioeconomic impacts. Thematic coding enabled the identification of recurring patterns, knowledge gaps, and emerging opportunities for advancing circular agriculture in Bangladesh. A limitation of this review is that it included only English-language, peer-reviewed studies with variable methodologies, which may not fully capture all local or unpublished evidence relevant to circular agriculture in Bangladesh.

Results and Discussion

Agricultural Waste Landscape in Bangladesh

Bangladesh, an agriculture-based country, generates a vast array of agricultural waste, which can be broadly categorised into crop residues, animal waste, and food/agro-industrial byproducts. Common types of crop residues include rice straw, jute sticks, maize stalks, sugarcane leaves, wheat straw, groundnut straw, and pulse straw, whereas animal waste primarily comprises manure and poultry litter (Miah et al., 2022). Table 1 presents the different types of agricultural waste in Bangladesh, along with their sources, utilisation patterns, and associated environmental concerns.

Table 1. Agricultural waste types, sources, utilisation patterns, and environmental concerns in Bangladesh.

Waste type/residue	Source crop/activity	Typical uses	Environmental concern if unused
Rice straw	Paddy fields (rice cultivation)	Animal feed, animal bedding, housing material, fuel, compost, biogas	Air pollution from burning
Rice husk	Rice mills	Poultry bedding, cattle feed, fuel	Adds to solid waste burden
Wheat straw	Wheat fields	Fuel, housing material	Air pollution from burning
Jute sticks/stalks	Jute fibre processing	Fencing, fuel, biochar, housing material	Landfill clogging, decay
Groundnut straw	Groundnut cultivation	Fuel, animal feed	Decomposes, attracts pests if dumped
Vegetable plants/peels	Agro-processing units, vegetable farms, households	Compost, biogas, fuel, animal feed	Attracts pests, decomposes in dumps
Pulse straw	Pulse crops	Fuel, animal feed	Decay, contributes to solid waste
Sugarcane leaves	Sugarcane farms	Fuel, animal feed	Decomposition-related emissions
Sugarcane bagasse	Sugarcane mills	Fuel	Waste burden if not reused
Maize leaf and straw	Maize cultivation	Fuel, animal feed	Attracts pests and waste burden
Maize husk	Maize processing	Fuel	Adds to solid waste burden
Poultry litter	Broiler/layer poultry farms	Organic fertiliser, biogas	Water contamination, odour
Cow dung	Dairy farms, cattle sheds	Biogas, compost	Methane emissions

Source: Authors’ systematisation based on published literature.

In addition, vegetable peels, kitchen waste, and rice husk are also generated in significant quantities from agro-processing and household activities (Baker et al., 2017). On average, farm households produce approximately 822 kg of agricultural waste monthly, depending on the type of farming activity and seasonal variation. These wastes are mainly used in rural areas for cooking fuel (57.06%), animal feed (68.04%), cow dung ball preparation (61.86%), composting, and reuse in subsequent cultivation cycles (Islam et al., 2022). Figure 2 illustrates the daily waste generation in Bangladesh, while Figure 3 shows the composition of agricultural residues.

Estimated composition of waste in Bangladesh

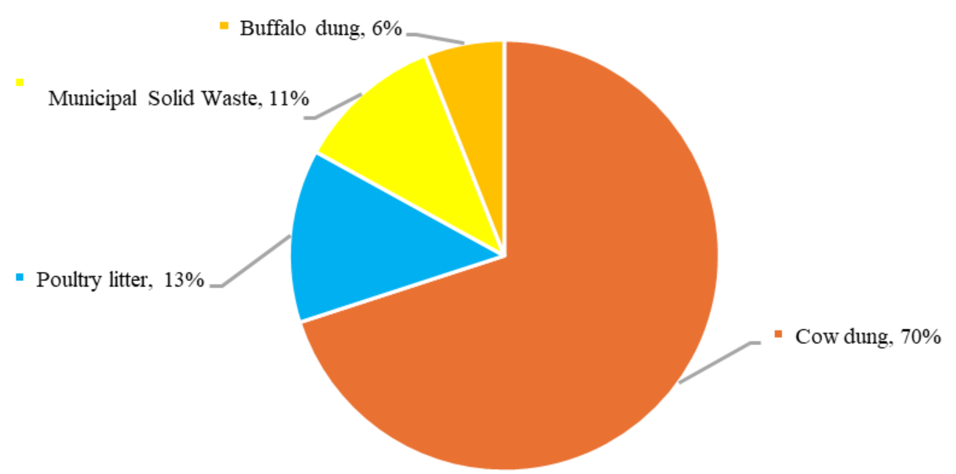

Figure 2. Waste generation per day in Bangladesh.
Source: Adapted from Karmaker et al., 2020.

However, owing to the lack of appropriate collection systems and technologies, approximately 29–100% of crop residues are left to rot or are burned in the field, while most manure and poultry litter are either dumped in pits or used in traditional, unregulated ways (Alam and Ahmade, 2013). This inefficient and often unscientific utilisation not only leads to resource underuse but also causes severe environmental issues. Poor agricultural waste management contributes significantly to greenhouse gas (GHG) emissions, including methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), which arise from open burning and unmanaged decomposition processes (Zalidis et al., 2002; Josimovic et al., 2015; Steinmetz et al., 2016; Pardo et al., 2017; Dai et al., 2018; IPCC, 2022). The long-term improper application of poultry manure further results in elevated atmospheric ammonia and accumulation of microelements, increasing the bioavailability and toxicity of metals in the environment (Zhang, 2012; Vrzel et al., 2016; Fan et al., 2020; Rahman et al., 2022).

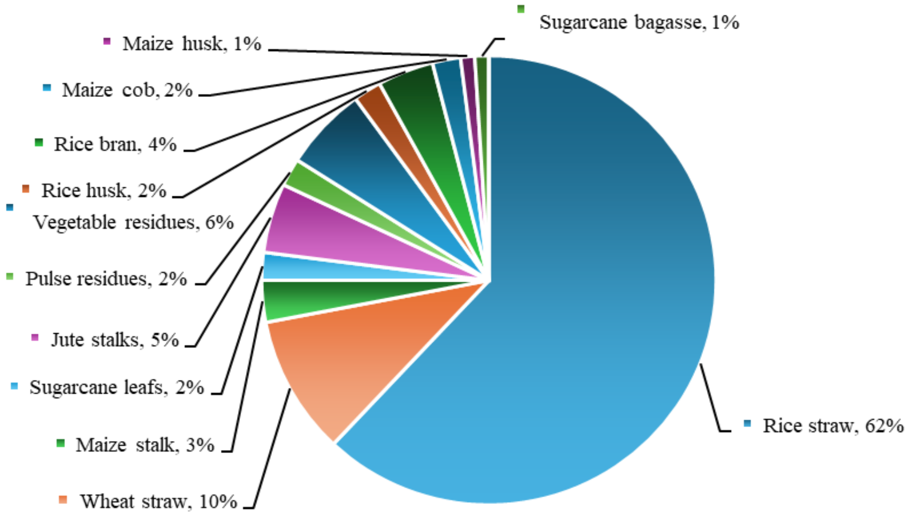

Figure 3. Composition of agricultural residues in Bangladesh.
Source: Adapted from Halder, 2014.

In terms of soil health, persistent residue burning depletes soil organic matter, reduces microbial diversity, disrupts nutrient cycles, and ultimately decreases soil fertility and crop productivity (Atinkut et al., 2020). Furthermore, leachate from inadequately stored manure and decomposed waste leads to contamination of surface and groundwater sources, causing eutrophication, fish mortality, and health risks for local communities, especially in areas with poultry farms located near water bodies, which become particularly hazardous during the monsoon season (DCC, 2004; Oyedotun et al., 2021). Table 2 summarises the waste generation trend in Bangladesh over the years, highlighting its rapid escalation.

Table 2. Waste generation scenario in Bangladesh.

Year	Waste generation (tonnes/day)
1991	9,873.5
2001	11,695
2015	27,492
2025	47,064 (projected)

Source: Adapted from SREDA, 2020.

This escalating trend in waste generation from 9,873 tonnes/day in 1991 to a projected 47,064 tonnes/day by 2025 highlights the urgent need for sustainable waste management solutions. Addressing these interconnected issues through effective waste-to-value strategies and circular bioeconomy models is crucial for ensuring environmental sustainability and agricultural resilience in Bangladesh.

Waste-to-Value Strategies in Circular Agriculture

Agricultural residues, including crop waste, livestock manure, and urban organic waste, present both challenges and opportunities for sustainable agriculture (Ioannou et al., 2015; Shinde et al., 2022; Koul et al., 2022). Globally, millions of tonnes of crop residues are generated annually, and in Bangladesh alone, urban areas produce approximately 4.86 million tonnes of organic waste each year, 75–85% of which is biodegradable (Aminul, 2005; Sujauddin et al., 2008; Guerrero et al., 2013). Proper management of these wastes through circular agricultural approaches such as composting, vermicomposting, bio-fertilising, and biochar production can increase soil fertility, reduce environmental pollution, and improve crop productivity. In Bangladesh, several practical waste-to-value strategies can be implemented to strengthen circular agricultural systems. The most promising approaches are as follows:

(1) Composting is a controlled biological process in which organic substrates are decomposed by microorganisms, producing nutrient-rich compost suitable for agricultural use (Haug, 1980). In Bangladesh, composting urban and agricultural waste offers a natural alternative to chemical fertilisers, improving soil structure, aeration, and fertility. High-quality compost requires optimal feedstock selection and a balanced carbon-to-nitrogen (C:N) ratio, typically 10:1–20:1, which combines carbon-rich "brown" materials with nitrogen-rich "green" materials (Huang et al., 2004; Gajalakshmi and Abbasi, 2008; Hubbe et al., 2010; Bernal et al., 2009). Composting proceeds through three microbially driven phases mesophilic, thermophilic, and maturation resulting in stabilised, pathogen-free compost suitable for storage and application (Büyüksönmez et al., 2000; Sundberg et al., 2004; Novinsak et al., 2008; Zeng et al., 2011). Despite its potential, large-scale composting in Bangladesh remains limited due to technical, institutional, and training constraints, with only a few facilities treating substantial waste volumes (Zurbrügg et al., 2005; Cofie et al., 2014).

(2) Vermicomposting is a biologically efficient and eco-friendly method of converting organic waste, particularly livestock manure and crop residues, into nutrient-enriched fertiliser via earthworms and associated microorganisms (Kumar et al., 2014; Ibrahim et al., 2024). Earthworms modulate microbial communities, secrete nutrient-rich mucus, condition substrates, and regulate pH, thereby increasing nitrogen (N), phosphorus (P), and potassium (K) contents in the final

product (Kumar et al., 2017). This process bypasses the thermophilic stage, producing homogenised, stable, and high-quality compost in 45–60 days while conserving water, energy, and land (Whiston and Seal, 1988; Syers et al., 1979; Eastman, 1999; Azis et al., 2022; ESF, 2006; Sakthivel, 2012).

(3) Biofertilisers complement composting and vermicomposting by increasing soil fertility and nutrient availability through beneficial microorganisms (Vessey, 2003). They improve root development, nutrient uptake, and plant growth while reducing dependency on chemical fertilizers and pesticides by up to 60% and increasing crop yields by 20–35% (Basak et al., 2015; Singh et al., 2021; Dai et al., 2004). In Bangladesh, biofertiliser adoption is gradually increasing, supported by initiatives from BINA, RDA, and NGOs such as PROYASH, although barriers including limited awareness, training, and access remain (Hasan et al., 2025). The combination of compost, vermicompost, and biofertilisers can have synergistic effects, improving soil health, nutrient cycling, and crop productivity.

(4) Biochar production via the pyrolysis of crop residues, urban organic waste, or livestock manure offers an additional waste-to-value strategy (Singh and Sidhu, 2014). Pyrolysis converts biomass into a stable, carbon-rich product that enhances soil fertility, water-holding capacity, and microbial activity while sequestering carbon for long periods and mitigating greenhouse gas emissions (Whitbread et al., 2003; Warnock et al., 2007; Nematian et al., 2021). Biochar can also act as a nutrient reservoir, improving fertiliser-use efficiency and crop performance, with reported yield increases of up to 30% in rice, chilli, cabbage, and kohlrabi (Ali et al., 2015; Ali et al., 2019; Karim et al., 2020; Karim et al., 2025; Sutradhar et al., 2021). Co-application with compost or reduced nitrogen fertiliser further reduces ammonia emissions and increases nutrient availability (Ferdous et al., 2023). Historically, biochar has been used in Amazonian Terra Preta soils and in modern applications through low-cost stoves and pyrolysis units, offering the dual benefits of energy production and soil amendment (Cui, 2015; Lehmann, 2009; Barrow, 2012; BBI, 2015; Magnusson, 2015). Collectively, these strategies-composting, vermicomposting, biofertilisers, biochar production, biogas generation, and integrated waste recycling enable circular agriculture by converting organic waste into valuable inputs that improve soil health, reduce environmental impacts, increase crop productivity, and support sustainable farming practices. In Bangladesh, scaling these approaches through awareness programmes, farmer training, technological adoption, and research on long-term impacts can significantly strengthen sustainable agricultural systems while addressing waste management challenges (FAO, 2010; Scholz et al., 2014; Duer, 2004).

Crop Residue Management in the Circular Economy

There are several ways to utilise crop residues produced at different stages of agricultural operations, as practisced by developed nations (Bhuvaneshwari et al., 2019). The most common applications include incorporation into soil, use as livestock feed, mulching materials, production of bioenergy, and even rural construction materials (Tenelli et al., 2021; Duan et al., 2021; Win et al., 2021). During tillage operations, crop residues, straw, or stubble are mixed with the topsoil to promote faster degradation and reduce surface residues, thereby facilitating intercultural operations (Lohan et al., 2018). Crop residue management can also help mitigate climate change impacts, particularly for crops grown after the wet season, by improving water use efficiency (Liu et al., 2017). In wheat cultivation, for example, the use of rice straw combined with fertiliser application has been shown to improve soil pH, microbial population, and enzymatic activity (Chowdhary et al., 2020), whereas residue reuse has been associated with an average yield increase of approximately 5% (Lu, 2020). The surface retention of straw, trash, leaves, and other plant parts as mulch conserves soil moisture, enhances organic carbon recycling and nutrient availability, ultimately improving input use efficiency, minimising soil erosion, and increasing productivity (Wu et al., 2021). In developing countries, a significant portion of crop residues is still used as feed for domestic animals, with leguminous residues providing higher crude protein and nutrient contents than rice straw does; the palatability of different residues depends on their lignocellulose and nutrient composition (Devi et al., 2017; Win et al., 2021). Additionally, the use of cereal straw as a roof material is a common rural practice, and the production of building materials such as straw–clay bricks and walls has been a traditional method for generations (Zhao et al., 2014). In Bangladesh, crop residues are traditionally managed through burning, mulching, or use as fodder and fuel, although burning notably causes air pollution and results in the loss of valuable organic matter. Sustainable alternatives such as incorporating residues into the soil, composting, and converting them into bioenergy are being promoted for their benefits in improving soil fertility, enhancing carbon sequestration, and reducing greenhouse gas emissions. Technological interventions, including residue collectors, shredders, and microbial inoculants, help streamline residue processing and accelerate nutrient cycling. These circular practices can reduce dependence on chemical fertilisers, lower emissions, and increase productivity. However, yet adoption remains limited by challenges such as a lack of technological access, insufficient awareness, and financial constraints which could be addressed through education, policy support, and infrastructure development.

Biogas Production from Agricultural Residues in Bangladesh

Agriculture employs approximately 80% of Bangladesh's population, generating significant quantities of crop residues and organic waste materials (Tasnim et al., 2017). With nearly 87% of households dependent on biomass energy, these agricultural residues constitute crucial resources for renewable energy generation (Rahman et al., 2018). Bangladesh is also experiencing severe energy shortages but possesses considerable potential for the development of renewable energy, particularly biomass, solar, hydro, and wind power. Efforts by government bodies and NGOs have promoted technologies such as biogas systems, improved cooking stoves, and biomass briquettes, positioning renewable energy as a practical approach for rural development (Islam et al., 2008). Animal manure, particularly from dairy farms, produces an estimated 156 million tonnes annually (Huque et al., 2017), along with crop residues, which serve as primary substrates for anaerobic digestion (AD) processes to produce biogas (Khan and Martin, 2016). Despite the substantial biogas potential arising from Bangladesh's large poultry population, approximately 200 million birds, and extensive dairy farming, biogas utilisation in poultry farms remains minimal (Das et al., 2016). The predominant biogas technology employed is the brick-built fixed-dome digester, which is implemented primarily on the household scale. Survey data indicates that most digesters utilise single-manure feedstock, whereas poultry litter-based digestion yields comparatively lower biogas production efficiency (SREDA, 2021). By the end of 2020, an estimated 140,500 biogas plants were operating across Bangladesh, predominantly at the household scale; commercial-scale biogas facilities remain underdeveloped due to infrastructural and technical limitations (IDCOL, 2014; IDCOL, 2018). The Infrastructure Development Company Limited (IDCOL), established in 1997, financed over 56,500 small-scale biogas plants by 2020, facilitating renewable energy deployment through both domestic and international partnerships (Sovacool and Drupady, 2011). Since 1996, Grameen Shakti has also played a pivotal role in expanding renewable energy access through the installation of solar systems, cookstoves, and biogas plants, positively impacting millions. However, challenges related to staffing, cost, political factors, and awareness persist (IDCOL, 2018). In Bangladesh, Infrastructure Development Company Limited (IDCOL) and Grameen Shakti are working together to develop several biogas plants with plans to establish approximately 80,000 small biogas plants. The government of Bangladesh also aims to establish a 1 MW biomass-based plant and 5 MW biogas-based plants in different regions (Power Cell, 2019). Financial assessments indicate that small-scale biogas plants are economically feasible, offering positive returns and adequate energy for typical household consumption (Hossain et al., 2020; Bedana et al., 2022). Data suggest that approximately 106 million tonnes of biomass can produce more than 5 billion cubic meteres of biogas annually, with 6 m^3 biogas plants identified as the most viable for rural applications (Sarker et al., 2020). Livestock-associated greenhouse gas emissions have increased, yet the utilisation of urban livestock waste for biogas could reduce emissions by 37.5% by 2050. On a national scale, livestock waste can generate 27.9 billion m^3 of biogas, 50 TWh of electricity, and 29.2 million tonnes of organic fertiliser annually, aligning with climate goals and sustainable energy objectives. In 2016 alone, Bangladesh's 229 million tonnes of livestock waste had the capacity to produce nearly 17 billion m³ of biogas, potentially reducing CO_2 emissions by several million tonnes (Siddiki et al., 2021). According to the Bangladesh Biogas Development Foundation, cattle manure alone can generate approximately 77.4 million cubic meteres of biogas annually, equivalent to approximately 170,000 MWh of energy and displacing several million tonnes of fossil fuel consumption (ILMM, 2015). Common animal manures yield high biogas outputs, with methane concentrations ranging from 60% to 74% (Rahman et al., 2018). The optimal conditions for anaerobic digestion occur between 35 and 40°C, with cow dung delivering the highest yields of biogas and methane (Nandi et al., 2020). In refugee camps, biogas has successfully replaced significant quantities of LPG, achieving an 85% reduction in emissions (Chowdhury et al., 2022). Household biogas plants have been shown to reduce emissions by more than 80%, decrease CO_2 output significantly, replace conventional fuels, and produce nutrient-rich fertiliser, highlighting their environmental, economic, and social benefits (Rahman et al., 2019).

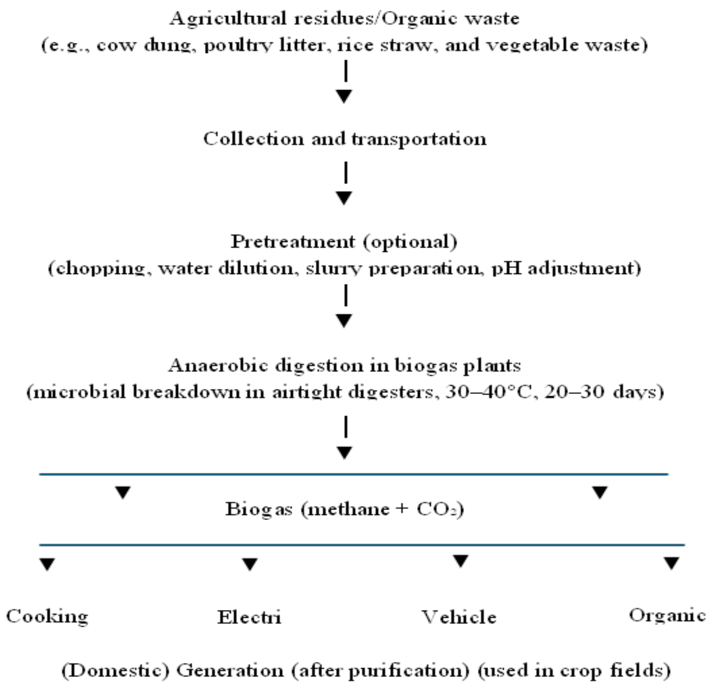

Figure 4. Biogas production process from agricultural residues in Bangladesh, showing key steps from waste collection to biogas and organic fertiliser utilisation. Source: Developed by the authors based on information synthesised from multiple studies on biogas production and agricultural waste management.

Biogas production not only provides a sustainable energy source, but also produces nutrient-rich bio-slurry, a valuable organic fertiliser that enhances soil fertility and reduces reliance on synthetic chemical fertilisers, thereby improving crop yields and farmer livelihoods (Parawira, 2009; Ch'ng et al., 2014). Nevertheless, improper management and disposal of bio-slurry can lead to adverse environmental and health impacts (Khanam et al., 2019). The overall process of biogas generation from agricultural residues, including collection, pretreatment, anaerobic digestion, and subsequent utilisation of both biogas and bio-slurry, is illustrated in Figure 4. Untreated poultry litter is a major source of greenhouse gas emissions, which can be reduced by 65% through anaerobic digestion, with additional reductions achieved by applying digested slurry as bio-fertiliser (Mainali et al., 2017). However, the expansion of biogas technology faces challenges, including limited user awareness, high capital and operational costs, technical malfunctions, and inadequate maintenance and training services (Muñoz, 2019; Huque et al., 2017). Although advanced monitoring and control systems can increase biogas production by up to 75%, their cost remains prohibitive for most rural farmers (Islam et al., 2014). Despite the considerable biogas potential within rural households and poultry operations, uptake remains limited (Sarker et al., 2020).

While poultry waste composting and biogas production provide environmental benefits, improving knowledge and investment remains critical (Rahman et al., 2022). The full benefits of biogas technology necessitate improved farm management, optimised feedstock handling, and effective waste management strategies to integrate diverse agricultural residues, such as manure, bedding materials, hatchery waste, kitchen scraps, and processing byproducts (John and Teto, 2013; Nasrin et al., 2021; Nasiruddin et al., 2020; Muduli et al., 2019). Bangladesh's abundant biomass resources—comprising crop residues, animal manure, and solid waste are increasingly being tapped through supportive initiatives (Huda et al., 2014). However, current policies largely emphasize household-scale biogas systems, highlighting the need to support commercial-scale ventures (Islam et al., 2021). For example, slaughterhouses in Dhaka alone can generate approximately 2.15 million m^3 of biogas annually, which can be used for heating, electricity, or biomethane (Salehin et al., 2021). Community biogas plants utilising dairy manure can produce 31 million m^3 of biogas annually, generate 200.6 GWh of electricity, reduce greenhouse gas emissions substantially, and increase the nation's renewable energy share by 1.25% (Aktar et al., 2024). Similarly, livestock waste from Chattogram holds significant promise for bioenergy (Das et al., 2023). Thermal conversion via the pyrolysis of rice straw and plastic waste has shown promise as an effective waste-to-energy method. However, farmers need training to improve their waste recycling capacity (Islam et al., 2021; Kabir et al., 2023). While agricultural waste is plentiful at the household level, limited knowledge of scientific composting restricts its utilisation. Enhancing composting practices could lower fertiliser costs and advance sustainable agriculture (Miah et al., 2022). Geospatial analyses have identified 558 optimal sites for large-scale biogas plants, which can collectively produce 7,683 GWh of electricity and reduce greenhouse gas emissions by 6,636 Gg CO_2 annually (Mahal and Yabar, 2025). Agricultural residues alone could supply 9.7 billion m^3 of biogas, potentially fulfilling almost 88% of the country's energy requirements (Rahman et al., 2018). Moreover, integrating agriculture, forestry, and livestock systems offers opportunities to advance sustainable development goals, although resource constraints and gender disparities must be addressed (Datta et al., 2024). Although considerable potential exists, challenges such as insufficient research and development, fragmented coordination, low public awareness, and a lack of tariffs feedback, hinder broader biogas adoption. Nevertheless, the country's extensive waste-to-energy capacity and climate adaptation priorities create clear opportunities for growth (Hasan et al., 2022).

Circular Agriculture in Bangladesh: Policy, Institutions, and Future Prospects

Bangladesh has made significant strides in establishing policies and institutional frameworks to promote circular agriculture, emphasising waste-to-value strategies such as biogas production and crop residue management for sustainable growth. Key national policies, including the National Agricultural Policy (2012), Industrial Policy (2016), and Renewable Energy Policy (2008), along with strategic plans such as the Eighth Five-Year Plan and Bangladesh Delta Plan 2100, advocate efficient resource use, renewable energy adoption, and circular bio-economy initiatives such as composting and jute innovation (IEA, 2025; Reuters, 2025; MoEFCC, 2023). Regulatory bodies such as the Sustainable and Renewable Energy Development Authority (SREDA), together with waste management rules (D'Costa et al., 2022), operationalise the 3R (reduce, reuse, recycle) approach and extended producer responsibility (EPR) mechanisms. These efforts are supported by the Ministry of Environment, Forest and Climate Change and international partners (FICCI, 2024; IIBD, 2024; UNDP, 2025). NGOs, including Grameen Shakti, RDA, BRAC, RSF, BBF, GIZ, ISDE, and BEES, provide technical support, microfinance, and farmer training for digester installation, composting, and residue management (Sarker et al., 2020; Uddin et al., 2019; BEES, 2024). Community-led initiatives, such as the engagement of religious leaders by ATEC, have successfully addressed social barriers to adoption (The Business Standard, 2024). To accelerate adoption, Bangladesh can draw on international best practices, such as India's training models promoting composting and bio-decomposers (Krishi Jagran, 2024). Embedding circular agriculture into formal education and extension programmes can further enhance awareness.

Currently, awareness of 3R principles and conservation agriculture remains limited (Kabir et al., 2023), highlighting the need for strengthened extension services, capacity building, and public engagement.

Conclusion

Circular agriculture in Bangladesh transforms livestock manure, crop residues, and organic waste into valuable resources through biogas production, composting, vermicomposting, biofertilisers, and biochar, enhancing soil fertility, crop productivity, and renewable energy generation. These waste-to-value strategies reduce environmental pollution, mitigate greenhouse gas emissions, and support rural livelihoods while promoting efficient resource utilisation. Scaling up adoption requires strengthened policies, institutional capacity, extension services, and active community engagement to support sustainable agricultural development. Although Bangladesh has established a supportive policy and institutional framework, key challenges remain, including limited infrastructure, inadequate social outreach, financial constraints, and low field-level adoption. Addressing these barriers through targeted incentives, technology integration, improved extension services, and inclusive stakeholder collaboration is essential for advancing circular agriculture and achieving sustainable growth. Better utilisation of Bangladesh's abundant biomass resources, particularly crop residues and livestock manure, can significantly strengthen renewable energy production and sustainable soil management. Expanding decentralised biogas systems, promoting crop residue valorisation, and enhancing organic waste recycling can contribute to rural energy security and environmental protection. Increasing farmer training, awareness programmes, and access to appropriate technologies will further support wider adoption. Future research should focus on evaluating the long-term impacts of compost, biochar, and biogas slurry on soil health and crop productivity across different agro-ecological conditions in Bangladesh. Additional studies are needed to optimise biomass conversion technologies and assess their environmental and socioeconomic feasibility to support large-scale implementation of circular agriculture.

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UTICAJ CIRKULARNE POLJOPRIVREDE U BANGLADEŠU: STRATEGIJE STVARANJA VREDNOSTI IZ OTPADA U PROIZVODNJI BIOGASA I UPRAVLJANJU BILJNIM OSTACIMA

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R e z i m e

Cirkularna poljoprivreda (CP), proistekla iz principa cirkularne ekonomije (CE), promoviše resursno efikasne i sisteme zatvorene petlje u poljoprivredi u kojima se organski otpad pretvara u obnovljivu energiju, đubriva i sredstva za poboljšanje zemljišta. U Bangladešu, neadekvatno upravljanje stajnjakom, biljnim ostacima i organskim otpadom doprinosi emisijama gasova, degradaciji zemljišta i zagađenju životne sredine, što ukazuje na potrebu za strategijama stvaranja vrednosti iz otpada. Ovaj rad procenjuje uticaj cirkularne poljoprivrede u Bangladešu, sa posebnim naglaskom na upravljanje biljnim ostacima i proizvodnju biogasa kao ključnim putevima za oporavak resursa i proizvodnju obnovljive energije. Pregled literature sproveden je na osnovu 102 naučna rada i zvaničnih dokumenata kako bi se procenle postojeće prakse, tehnološke mogućnosti i okviri javnih politika. Strategije stvaranja vrednosti iz otpada, uključujući kompostiranje, proizvodnju biođubriva, proizvodnju bioćumura i anaerobnu digestiju omogućavaju pretvaranje poljoprivrednih ostataka u sredstva za poboljšanje zemljišta bogata hranljivim materijama i obnovljivu energiju, čime se unapređuje plodnost zemljišta, povećava produktivnost useva i smanjuje zavisnost od mineralnih đubriva. Bangladeš proizvodi više od 106 miliona tona biomase godišnje, sa potencijalom za proizvodnju preko pet milijardi m³ biogasa. Međutim, većina sistema za proizvodnju biogasa i dalje je mala zbog tehnoloških, finansijskih i ograničenja vezanih za svest. Proširenje cirkularne poljoprivrede kroz integrisano upravljanje stajnjakom, biljnim ostacima i organskim otpadom moglo bi smanjiti emisije gasova, unaprediti zdravlje zemljišta i ojačati energetsku sigurnost ruralnih područja. Jačanje izgradnje kapaciteta, transfera tehnologija, zelenog finansiranja i javno-privatne saradnje od ključnog je značaja za primenu cirkularne poljoprivrede i podršku održivim poljoprivrednim i energetskim sistemima u Bangladešu.

Ključne reči: strategija stvaranja vrednosti iz otpada, upravljanje biljnim ostacima, proizvodnja biogasa, održiva poljoprivreda.

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