

Unraveling the Challenges of Waste -to-Energy Transition in Emerging Economies: Implication for Sustainability

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Abstract

The recent geopolitical events, such as the conflict between Russia and Ukraine have strained the available resources worldwide. In emerging economies like Bangladesh which is heavily reliant on imported gas, oil and coal, this has created a severe energy crisis. In response to the energy crisis and to support eco-friendly waste management, converting waste into energy is being recognized as a promising solution. However, introducing waste-to-energy systems in developing economies faces many intricate challenges that require careful examination. This study therefore, aims to explore and evaluate the challenges associated with adopting a waste to energy (WtE) conversion system in emerging economies like Bangladesh. The research methodology involves identifying challenges from an extensive review of existing literature and expert feedback and then combining Bayesian theory with Best Worst Method (BMW) to evaluate the challenges. Among the 21 challenges analyzed, the “need for well-developed planning and incentivized policy making”, ‘ineffectiveness in waste segregation at the source’, and “high cost for installation, maintenance and infrastructure development appear to be the most significant challenges with weight values 0.071, 0.067 and 0.066 respectively. The study can enhance managers’ understanding of the challenges faced by this sector and thus facilitate informed decision-making. The outcomes of this study are expected to enrich the existing body of knowledge, promote the diffusion of WtE technology in emerging economies, reduce dependency on the international energy market and achieve global sustainable development goals (SDGs) such as affordable and clean energy (SDG7), sustainable cities and communities (SDG11) and climate action (SDG13).

Keywords: *Waste-to-energy, Renewable energy, Emerging economy, Sustainable development, Bayesian best worst method*

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Background to the Study

Waste generation is a significant environmental challenge that is rapidly increasing globally. As the global population is anticipated to increase in the coming decades, there is a projected surge in waste generation at an unprecedented pace. In recent years, the acceleration of urbanization, industrialization, and economic growth has led to an intensified pace of waste generation. Municipal solid waste (MSW) among various waste types has emerged as the most substantial contributor (Islam, 2016). MSW includes waste originating from residential, institutional, and industrial sources and comprises a vast array of substances, including food and vegetable waste, paper, plastics, metals, glass, textiles, wood, grass, leaves, and various organic and inorganic substances (Samarasiri et al., 2017). The amount of waste generated globally is truly astounding, with the World Bank estimating an annual production of almost 1.3 billion tons of MSW, and this figure is predicted to rise to 2.2 billion tons by 2025 and further escalate to 2.59 billion tons per year by 2030 (Kumarasiri & Dissanayake, 2021). By 2050, it is predicted that the annual MSW generation will reach a staggering billion tons, presenting a formidable environmental challenge (Sharma & Jain, 2020).

The inadequate management of MSW has significant detrimental effects on both the natural environment and biodiversity and the well-being of people, particularly in the least developed and developing nations like India, China, Bangladesh, Thailand, and Malaysia (Islam, 2018). The swift expansion of the population, along with speedy industrialization and urbanization, has resulted in the generation of large quantities of waste that pose significant challenges in terms of proper handling and disposal. A substantial portion of MSW is disposed of through open dumping in landfills, leading to soil and water contamination and air pollution caused by waste incineration. These activities harm the local environment and human health, leading to respiratory problems and other diseases (Adnan et al., 2021). Furthermore, landfills produce significant methane, a potent greenhouse gas contributing to climate change. Worldwide, MSW generation has resulted in the release of 550 million metric tons of methane emissions each year, exacerbating the effects of climate change (Korai et al., 2016).

Historically, MSW management relied on open landfills and burning, causing environmental issues, but contemporary approaches emphasize sustainability through practices like recycling and incineration (Barma & Modibbo, 2022b). The efficient management and disposal of MSW pose substantial challenges for municipal and city corporations' authorities in many developing nations like Bangladesh, primarily due to the continuous waste generation and the associated huge costs of handling it (Cucchiella et al., 2017; Rahman et al., 2017).

In Bangladesh's urban areas, the annual waste production is estimated to be around 633,129 tons, which is equivalent. MSW is recognized as a renewable energy source alongside hydro, solar, wind, and other clean energy forms by The United States Environmental Protection Agency (EPA) (Zhang et al., 2015). In addition to the challenges in waste management, Bangladesh also faces energy shortages due to its heavy reliance on imported fuels. The ongoing Russia-Ukraine conflict and rising oil prices have resulted in an energy crisis in the country, with frequent power outages and load shedding affecting households and businesses. Considering the prevailing circumstances, the conversion of MSW into energy holds promise

as a potential solution to address both the waste management and energy challenges in Bangladesh. The government has acknowledged the significance of the Paris Agreement, 2015 and Sustainable Development Goals (SDGs) (Debnath et al., 2023d; Kabir & Khan, 2020).

Even though Bangladesh has recently advanced from a least developed country to a developing one, its energy sector is still very reliant on the international energy market, especially for fossil fuels (Limon et al., 2023). According to the most recent Bangladesh Power Development Board report, 53.02% of electricity in Bangladesh is generated by natural gas-based power plants, with the remaining 46.97% coming from a combination of HFO, high-speed diesel (HSD), imported power, hydropower, coal, and solar power, accounting for 25.51%, 6.14%, 5.54%, 1.1%, 8.06%, and 0.62% respectively (Akter et al., 2022). However, the country is now trying to move away from the fossil fuel intensive electricity generation mix to comply with the global decarbonization initiatives (Debnath et al., 2023c). Embracing decarbonization technologies in the energy sector is very important to curtail CO₂ emissions and move toward a low-carbon future (Debnath et al., 2023c). Among various sources of clean energy, waste to energy (WtE) is recognized as a renewable energy source that efficiently converts discarded municipal solid waste (MSW) into electricity and heating steam, making it a more sustainable alternative to land filling with reduced land requirements and solid waste volume (Hou et al., 2019). Proper handling of MSW poses a significant challenge for a developing nation like Bangladesh. Adopting WtE can be a good solution to both the MSW management problem and the ongoing energy crisis.

The successful WtE conversion can significantly contribute to the achievement of multiple SDGs. Firstly, by ensuring a green energy source at a lower cost, WtE technologies contribute to SDG 7 (Affordable and Clean Energy). Furthermore, implementing WtE requires infrastructure and capital, thereby promoting innovation and the development of industries, aligning with SDG 9 (Industry, Innovation, and Infrastructure). Moreover, WtE technologies help reduce waste in land-fills and the environment, thereby promoting the practice of consuming and producing goods and services that minimize negative impacts on the environment and society and support SDG 12 (Responsible Consumption and Production). Additionally, by capturing methane produced from organic waste in landfills and reducing waste that would otherwise be burned or left to decay, WtE conversion aids in reducing greenhouse gas emissions, aligning with SDG 13 (Climate Action) and SDG 15 (Life on Land).

While transitioning to WtE, numerous challenges and complexities encompassing environmental, technological, economic, regulatory, and societal aspects arise that necessitate careful consideration and strategic planning. Numerous studies have focused on different aspects of WtE, such as environmental impact assessment (Dastjerdi et al., 2021), technological evaluation such as biological treatment, thermal treatment, landfill gas utilization and bio-refinery technologies, among others (Ali et al., 2020) and potential scenarios for enhancing climate co benefits. Within the vast and diversified field of WtE research, our study redirects the spotlight towards the critical but often overlooked aspect of

barriers and limitations that impede the successful implementation of waste-to-energy solutions in emerging economies like Bangladesh. By doing so, this study aims to contribute to the body of knowledge that can lead to formulating policies and strategies for a more sustainable and efficient WtE transition. Therefore, this study aims to fill the knowledge gap by answering the following research questions (RQs).

RQ1: What are the challenges that need to be addressed to implement the WtE transition in an emerging economy like Bangladesh?

RQ2: How can we evaluate the challenges involved in achieving energy sustainability?

RQ3: How can each challenge's relative importance impact the successful WtE transition in an emerging economy like Bangladesh?

RQ4: How can the study's findings be effectively appraised to guide decision-makers in implementing strategic measures to promote energy sustainability?

To answer the questions raised earlier, this study will attempt to fulfill the following research objectives (ROs):

RO1: To apply an integrated approach consisting of an extensive literature review and expert feedback to identify the challenges impeding the successful WtE transition from an emerging economy perspective.

RO2: To evaluate the identified challenges using an integrated multi-criteria decision making framework.

RO3: To assess the potential impact of the challenges on the successful WtE transition based on their relative importance obtained from the evaluation.

RO4: To provide crucial insights to decision-makers and policy makers based on the obtained results for efficient strategic planning to facilitate the successful WtE transition and promote energy sustainability.

To accomplish the previously stated ROs, this study proposes a structured framework to identify, prioritize and assess the challenges associated with implementing WtE conversion in Bangladesh. This framework involves the following steps:

- i. Conducting a comprehensive literature review to identify the challenges associated with WtE implementation in emerging economies like Bangladesh
- ii. Conducting interviews with pertinent stakeholders in Bangladesh to obtain a comprehensive understanding of the challenges involved and seek their feedback to verify the challenges identified in this literature review
- iii. Conducting a survey for analyzing challenges to collect data from experts in the field regarding the identified challenges
- iv. Analyzing the collected data using a multi-criteria decision making (MCDM)

- approach named the Bayesian BWM technique, which relies on pairwise comparisons to prioritize the identified challenges effectively
- v. Prioritizing the challenges based on the Bayesian BWM analysis

This study intends to address current hurdles and establish a trajectory for future researchers in the domain of WtE transition, thereby presenting a comprehensive roadmap for scholars and practitioners. Examining and understanding the challenges can facilitate the implementation of WtE technologies and the formulation of relevant long-term policies. The tangible outcomes of this study hold the potential to directly and substantially benefit the energy sector stakeholders. The study also can aid the policy makers, offering critical insights that can contribute to formulating effective and sustainable energy policies in the context of emerging economies. This work can also encourage the industry stakeholders to explore deeper and contribute further to the evolving landscape of WtE. The research therefore, can emerge as a valuable bridge between theoretical insights and practical applications, fostering a more informed and collaborative approach towards a sustainable future.

The rest of the paper is structured as follows: section 2 presents the literature review, section 3 describes the methodological approach of Bayesian BWM including the study context and data collection; section 4 exhibits the results; section 5 discusses the findings of the study and the study implications from theoretical, practical and sustainability context while section 6 concludes the study.

Literature Review

Currently, Bangladesh has a combined installed capacity of 26,550 MW for captive and renewable energy sources according to Power Cell (2023). However, there are plans outlined in Vision 2041 (Planning Division, 2020) and the power system master plan (Power Division, 2016) to increase this capacity to 40,000 MW by 2030 and 60,000 MW by 2041. According to the Integrated Energy and Power Master Plan (IEPMP) developed by the Japan International Cooperation Agency (JICA), it is anticipated that at least 40% of the 60,000 MW of electricity generated by 2041 in Bangladesh will come from clean energy sources. This aligns with Bangladesh's objective of achieving carbon neutrality by 2070 as stated in The Business Post (2022). The power sector is crucial for socio-economic development, fostering industrial growth and poverty reduction and renewable energy sources such as waste-to-electricity will play a significant role in achieving these targets (Ahmed et al., 2022).

The government of Bangladesh established the Sustainable and Renewable Energy Development Authority (SREDA) to tackle concerns related to global warming, environmental risks and energy security. SREDA works towards achieving these goals by reducing reliance on fossil fuels and promoting the adoption and expansion of various renewable energy sources. Additionally, SREDA focuses on reducing energy waste in residential and different industrial sectors through energy conservation and efficient utilization (SREDA, 2021). In Bangladesh, utilizing organic waste components such as plant residues, agricultural waste, organic fertilizer, food waste, animal manure, green waste, and other MSW for biogas production has emerged as an effective waste management system.

Biogas serves multiple purposes such as cooking and organic fertilizer for fishponds and crops. As of June 2020, 76,771 biogas plants have been established in Bangladesh and several programs and projects are being implemented to develop biogas plants further (SREDA, 2021). Poultry waste-based biogas plants have been the most successful in generating gas for electricity production and the remaining residue is a high-quality organic fertilizer for crops.

Despite the many benefits of biogas production, managing the waste (slurry) generated after biogas production remains a significant challenge in Bangladesh, as highlighted in the biogas guidelines (SREDA, 2020a, 2020b). Bangladesh has launched initiatives to develop projects that utilize appropriate technology to generate energy from waste and introducing the national 3R strategy, emphasizing the principles of 'Reduce', 'Reuse', and 'Recycle' to manage solid waste effectively, according to the United Nations Department of Economic and Social Affairs (UNDESA, 2021). The Bangladeshi government has started programs targeting using the right technology for WtE conversion, considering the rising volume of waste being produced and its potential as an energy source. Table 1 presents the ongoing development of WtE plants in Bangladesh.

Table 1: WtE plants (processing) in Bangladesh.

Plant Area	Technology	Capacity (MW) (Tons/Day)	Required Waste	Stakeholders Sources	
Aminbazar	Incineration	42.5	3000	Dhaka North City corporation, Bangladesh Power Development Board, and China Machinery Engineering Corp.	Daily Sun (2021)
Jalkuri	Incineration	6	600	Narayanganj City Corporation, Bangladesh Power Development Board, and Chinese Firm U and D.	The Financial Express (2022)
Matuail	Incineration	50	3000	Dhaka South City Corporation, Bangladesh Power Development Board, and Canvas Environmental Invest International Company Limited (China).	Daily sun (2021)

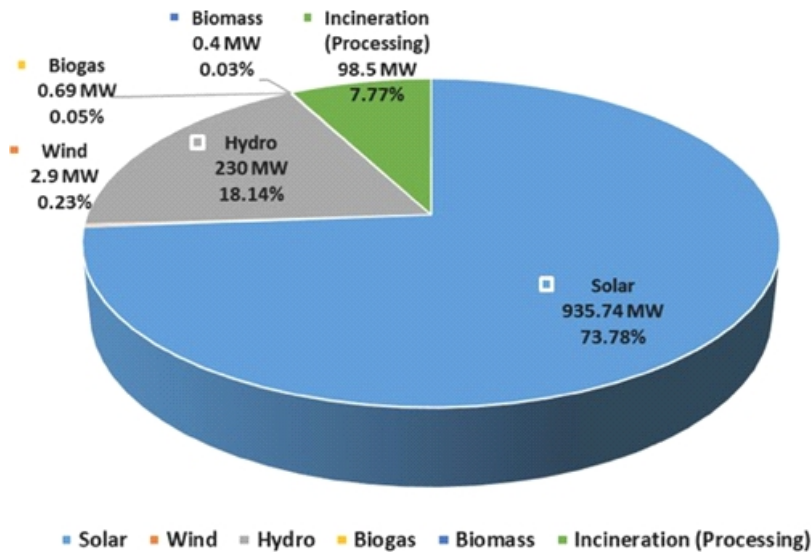


Fig. 1: Renewable energy sources in Bangladesh (SREDA, 2023)

Currently, Bangladesh's installed capacity of 26,550 MW includes 1169.73 MW (SREDA, 2023) from different renewable energy sources, mainly solar energy. Fig. 1 presents the percentage of power production using renewable energy sources in Bangladesh. With rising energy consumption, Bangladesh produced a total of 80,423 million kWh of net electricity during the fiscal year 2020–21 (Finance Division, 2022).

The Power Division is directing SREDA'S efforts to grow the waste-to-electricity industry, and city corporations and municipalities have embraced the strategy's guiding principles to improve their waste management procedures. In Bangladesh, WtE projects have been reviewed in six municipalities, including Mymensingh, Cox's Bazar, Dinajpur, Habiganj, Jashore, and Sirajganj to increase electricity production (SREDA, 2020a; 2020b). These locations can potentially use 300,504 tons of waste and generate 23,472 kWh in Modular Design 1, including indirect revenues, and 62,403 kWh in Modular Design 2 by energy reuse in a large-scale scenario. Implementing these projects can significantly contribute to national energy generation (United Nations Development Programme, 2018).

In that feasibility study report, the proposal for Modular Design 1 involves combining anaerobic digestion, recycling, and composting to create a biogas plant that handles organic municipal solid waste and can incorporate other waste treatment modules. The objective is to convert waste into useful and profitable end-products, including organic fertilizer and various forms of energy such as heat, gas, and electricity. Modular Design 2 incorporates anaerobic digestion, gasification and composting, specifically including a gasification module. The design involves pretreating the mixed solid waste stream to ensure it meets the technical specifications required for a downdraft gasifier. Like the first modular design, additional modules can be added to the site to treat other types of waste, maximizing the value of the products resulting from municipal solid waste treatment.

Related Works, Research Gap and Study Contributions

With a combined capacity of 37 and 50 million metric tons of waste respectively, there is potential to build 248 new WtE facilities within the European Union countries and 330 throughout Europe (Scarlat et al., 2019). The larger portion of the MSW in the US is sent to landfills that are fitted with gas recovery which is then used for electricity generation or supplied to homes and there are 86 WtE facilities in the US, primarily using incineration and refuse-derived fuel technologies (Mukherjee et al., 2020). A considerable increase in interest in using WtE technology in emerging economies has become important due to environmental and economic issues in recent years (Sadab et al., 2023). Numerous facets of the implementation of WtE projects in nations like Malaysia, Serbia, Nepal, and Bangladesh have been studied. In Malaysia for instance, Yong et al. (2019) investigated the environmental, monetary, and social difficulties related to energy recovery from MSW, while Serbia was used as an example in Vujic et al. (2015)'s analysis of the challenges connected with implementing WtE in emerging and transitioning nations. Adnan et al. (2021) presented 'Energy', 'Exergy', 'Exergoeconomic', and 'Environmental' (4E) analyses of thermal power plants for WtE applications in the Dhaka and Chattogram cities of Bangladesh. Mostakim et al. (2021) examined potential technologies for harnessing energy from waste produced in Bangladesh.

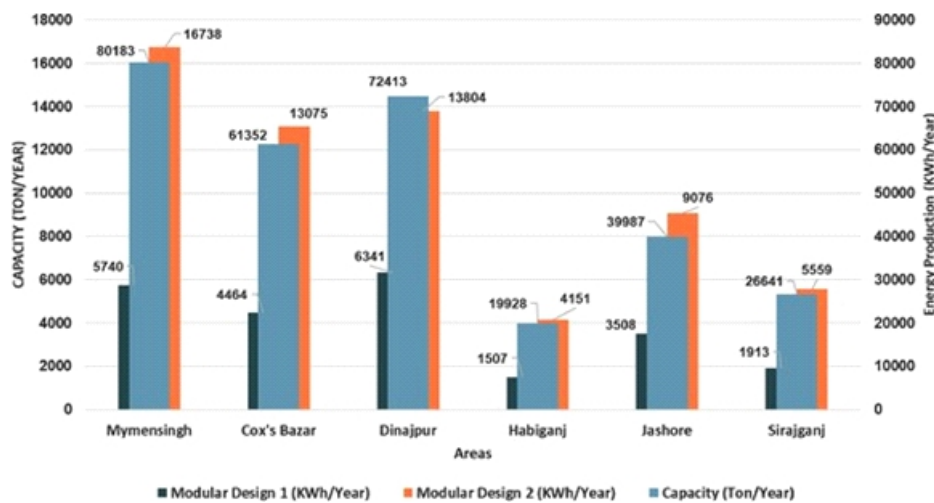


Fig. 2: Possible energy production in six municipalities of Bangladesh (United Nations Development Programme 2018)

This study offers four contributions. First, this study contributes to the existing literature by recognizing and analyzing the challenges for WtE in an emerging economy. By doing this, it is expected to make it easier for emerging economies to obtain sustainable and renewable energy. Second, it prioritizes the challenges by incorporating Bayesian theory and BWM, a more current and sophisticated method. To our current understanding, this is the first endeavor that combines Bayesian BWM, the developing economy, and challenges associated with the WtE transition under a single platform. Third, the study offers solutions to these problems, which might be useful information for researchers, industry participants, and governments who are

trying to promote renewable and sustainable energy in developing nations. Finally, this framework's contributions to attaining some of the SDGs, including SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), SDG 15 (Life on Land), etc., are numerous.

Key Challenges for WtE Implementation

An extensive literature search was conducted to identify the challenges to the WtE transition from the perspective of Bangladesh as a developing country. A systematic literature search protocol was used to identify the crucial challenges. Primarily, seventeen challenges were identified from the literature search.

Methods

This study aimed to comprehensively identify and prioritize challenges associated with Bangladesh's WtE transition. To achieve the study objective, this research employs a mixed methodical approach combining qualitative interviews with quantitative data analysis. First, after the initial identification of the challenges through an extensive literature review, systematic feedback from the expert was solicited to validate and refine the identified challenges. The combination of these methodologies allowed for integrating established knowledge and expert insights ensuring a comprehensive identification of the challenges. Numerous other studies have previously employed similar methodologies to identify relevant factors (Ali et al, 2022; Khan, Singh, et al.,2022; siraj, Debnath, Payel, et al.,2023; Zalvand et al.,2022). Subsequently, the Bayesian BMW was utilized to analyze the finalized challenges. The selection of the Bayesian BMW was motivated by its capacity to handle subjective judgement and uncertainties effectively. This method facilitated the aggregation of expert opinions and provided a structured approach for quantifying the relative importance of each identified challenge. Such a methodological choice aligns with the intricacies of the research objectives, particularly given the multidimensional aspects of the challenges (operational, economic, organizational and technical).

Study Context and Data Collection

As energy demand continues to increase globally, countries are turning to sustainable and renewable energy sources to address climate change and resource scarcity. WtE technology is one such renewable energy source that involves converting waste materials into useable forms of energy. WtE has the potential to address various operational, technical, managerial and economic challenges faced by emerging economies such as waste management, energy security, reducing reliance on fossil fuel and achieving the SDGs. Waste is a crucial focus of study's goal and objectives, thereby enhancing its accuracy and dependability. Purposive sampling is a purposeful, non-random approach that relies on the researcher's judgment regarding the pertinent information and their ability to identify experts capable of furnishing that information effectively (Siraj, Debnath, Kumar et al., 2023). The experts excluded no challenge. However, they added four more challenges: "Ineffectiveness in waste segregation at the source", "Heterogeneous mixture of waste at the dump site", "Insufficient financial backing from the government and investors" and "Complexity in the process of procurement". Additionally, they divided all the challenges into four clusters. Following the

literature review and expert validation assessment, 21 challenges were finally selected. The following stage involved contacting the same 12 experts to conduct semi-structured interviews to create the Best-to-Others and Others to Worst matrices. Semi-structured interviews are qualitative research techniques that combine pre-set open-ended questions with the freedom to probe further and cover new ground. The decision to employ semi-structured interviews with the experts was driven by the need for in-depth insights into the challenges associated with Bangladesh's waste-to-energy transition. A semi-structured interview process was chosen to allow a flexible yet systematic exploration of expert opinions, experiences and impressions. This method was considered appropriate for capturing nuanced information and facilitating a comprehensive understanding of the identified challenges (McGrath et al., 2019). Semi-structured interviews unlike unstructured ones, involve a guided interview process designed to address research objectives and focus on the conversation's natural flow rather than being strictly followed verbatim in the same order for each interview (Adeoye-Olatunde & Olenik, 2021). Moreover, the importance of ethical considerations in research is recognized in this process especially when involving expert participants. Informed consent was obtained from each expert before the commencement of the interviews. The participants were briefed on the purpose of the study, the voluntary nature of their participation and the confidentiality of their responses. The option to participate in either in-person interviews or via email was presented to respect the preferences and comfort levels of the experts. For email interviews, the questionnaire was provided through Google Forms. Participants were provided with a clear introduction outlining the study's objectives, the expected commitment and a statement ensuring the confidentiality of their responses. They were also informed that their insights would be aggregated and anonymized to maintain individual privacy.

Bayesian Best-Worst Method Approach

With the Bayesian BWM, a variation of the BWM, a group of elements (such as problems, requirements and alternatives) can be prioritized according to their perceived value or relevance. In the Bayesian BWM experts are asked to identify the “best” and “worst” criteria from a given set. These selected elements are then used as reference points for making pairwise comparisons during the analysis. It incorporates uncertainty into the model and increases the precision of the results by using Bayesian statistical approaches to estimate the relative weights of the items based on expert feedback (Mohammadi & Rezaei, 2020). The method has been widely applied in various fields, including marketing, environmental management and healthcare due to numerous advantages including flexibility in handling large-scale problems and incomplete data, probabilistic outputs and computational efficiency. The following steps are adopted for applying the Bayesian BWM approach, given as follows (Limon et al., 2023).

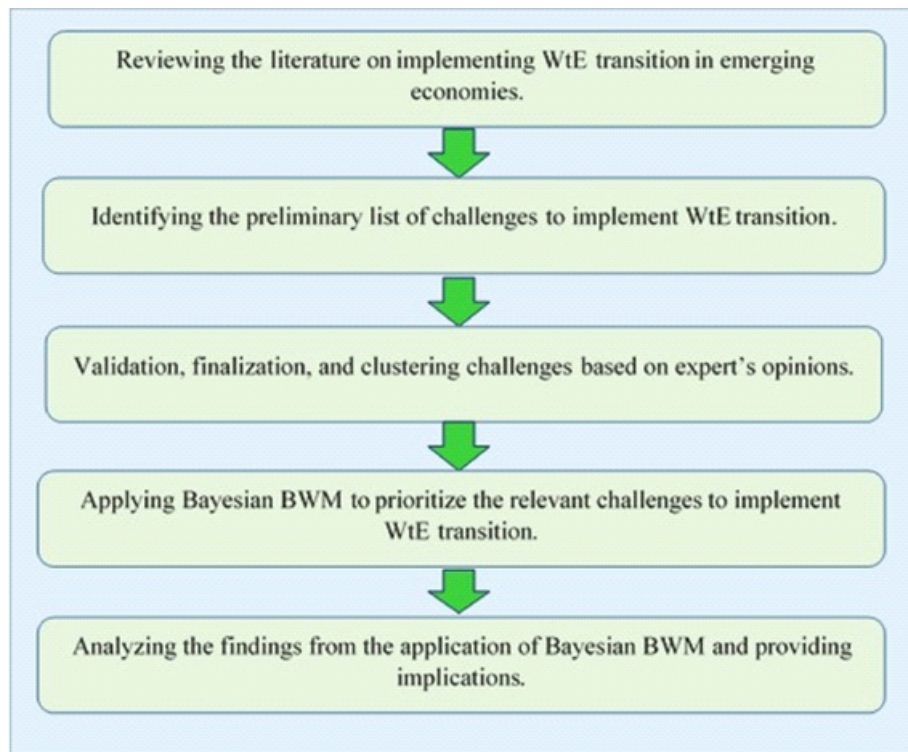


Fig. 3: Flow chart of the research methodology

Results

This section presents the outcomes of the ranking process applied to assess the challenges associated with the WtE transition in Bangladesh. Following the established steps of the Bayesian BWM experts identify the most significant (best) and least significant (worst) challenges from the given set. Subsequently, they formulate the “Best-to-Others” and “Others-to-Worst” vectors for both the main clusters and sub-clusters. By utilizing these vectors, the Bayesian BWM is employed to compute the overall weights assigned to each challenge. In this visualization, the nodes correspond to the criteria and their average weights. These average weights are calculated as the mean of the aggregated weight distribution derived from the input of all 12 experts. This consistent approach ensures a comprehensive and representative assessment of the challenges throughout the evaluation process.

The graph's edges indicate credal orderings, which show that with a given degree of confidence, one criterion is more important than another. Furthermore, the managerial challenges are found to be more important than the other clusters with a higher level of weight. Specifically, the managerial challenges are implemented with a 0.9 confidence level compared to economic challenges (0.81 confidence), technical challenges (0.54 confidence) and operational challenges (0.54 confidence).

The most significant managerial challenge is the 'need for well-developed planning and incentivized policy making' with a weight of 0.2472. The second most significant challenge is

the 'communication gap between the researchers and the government' with a weight of 0.1523 followed by the "inadequate engagement and collaboration from stake holders" with a weight of 0.1482. Other managerial challenges such as the 'inadequate engagement and collaboration from stake holders and the 'lack of comprehensive legislation and proper implementation' also have significant weight. Overall, the ranking of managerial challenges at the local level reveals which issues must be resolved to accomplish the WtE transition in emerging economies. It also presents the local ranking for the cluster of the operational challenges for the WtE transition in developing economies. According to the results, the most significant operational challenge is the 'ineffectiveness in waste segregation at the source' with a score of 0.2398. This is followed by 'proper site selection' with a score of 0.2297 and 'difficulty in swiftly managing waste collection and transportation' with a score of 0.1880. The remaining operational challenges, including 'Heterogeneous mixture of waste at dump site' (0.1719) and 'inappropriate methods for waste recovery and disposal' (0.1706), are found to be less significant.

The most significant technical challenge with a weight of 0.2392, is the 'lower calorific value compared to conventional fuels'. The second and third most significant challenges are the 'scarcity of integrated information on waste' (0.2141) and 'atmospheric damage in the plant areas' (0.1967), respectively. The local ranking provides valuable insights into the relative importance of technical challenges, which can be used to prioritize efforts and resources toward addressing the most significant technical challenges in the WtE transition process.

Discussion

According to the proposed Bayesian BWM framework, the main challenge in implementing WtE transition in emerging economies like Bangladesh is the "need for well-developed planning and incentivized policymaking (MC5)". Bui et al. (2022) identified this challenge as one of the most crucial challenges for successful conversion for WtE. This involves creating a comprehensive plan considering specific waste and energy needs and environmental and social impacts. Incentivized policymaking can support this planning process by offering financial incentives for sustainable WtE technologies, promoting job creation, reducing greenhouse gas emissions and attracting private sector investment (Qadir et al., 2021). Therefore, encouraging technology transfer and knowledge sharing is also important.

The "ineffectiveness in waste segregation at the source (OC1)" is the second significant issue noted in the report. Agbefe et al. (2019) evaluated the Ga West municipality's (Accra, Ghana) readiness to integrate waste segregation at source into its solid waste management in neighbourhood markets. Waste segregation is crucial for WtE technologies as different types of waste require different treatment processes. Failure to segregate waste properly can lead to contaminants, harmful emissions and the loss of valuable materials. Educating citizens about waste segregation and providing the necessary infrastructure and tools, such as separate waste bins, can effectively address this challenge (Sharma et al., 2020). The third important challenge is the "high cost associated with installation, maintenance, and infrastructure development (EC2)" of WtE plants. Due to the significant operational expenses of running these plants, developing countries still have trouble implementing this technology (Mani, 2020, pp. 147–184). The operating costs of these plants are often prohibitively expensive for many

communities in emerging economies. A lack of specialized equipment and skilled labor can further increase maintenance and repair costs. Policymakers can address this challenge by exploring alternative financing models, such as public private partnerships and community-based financing, to reduce the financial burden on the community.

Lastly, challenges such as the “shortage of proper amount of waste on time (EC4)”, “Lack of comprehensive legislation and proper implementation (MC7)”, “absence of operational personnel's knowledge and awareness (TC2)”, “insufficient financial backing from the government and investors (MC3)”, “complexity in the process of procurement (MC6)”, and “inadequate training and continual support (MC1)” are considered to be the least important challenges but should not be over-looked in the transition to WtE.

Theoretical Implication

The study broadens our understanding of WtE by investigating the connection between emerging economies, sustainable, and energy the MCDM approach. This MCDM framework, utilized in this study serves as a practical approach for assessing the main challenges associated with WtE conversion. This framework can be used by decision-makers in the energy sector to prioritize the challenges they need to address when implementing WtE projects. The study's identification of the most significant challenge to WtE conversion in emerging nations also emphasizes the necessity of considering the socio-economic and cultural aspects that may impact the success of WtE initiatives in these economic environments. The study's focus on exploring the connection between the WtE transition and emerging economies is especially relevant as these economies are experiencing rapid industrialization and urbanization increasing waste generation and energy demand. Overall, the study's theoretical contributions have implications for both academics and practitioners who are interested in the transition to sustainable and renewable energy in the energy sector. The study's findings can inform future researchers on WtE in emerging economies and guide the development of more effective policies and strategies for sustainable waste management.

Practical Implications

The study has significant practical implications for decision-makers, policymakers and stakeholders particularly in emerging economies where conventional energy sources are still dominant. By ranking the significant challenges and showing their hierarchical relationships, the framework can help decision-makers identify the most critical challenges to focus on when implementing WtE projects. This will enable them to develop effective strategies and policies to overcome these challenges and facilitate the transition to sustainable and renewable energy. For instance, the study's finding that the 'need for well-developed planning and incentivized policy making' is ranked first among all challenges suggests that policymakers should focus on this challenge at the early stage of the WtE transition process. This can help ensure that the necessary policies and regulations are in place to support adopting WtE technologies. Subsequently, policymakers can address other challenges identified by the framework to facilitate the WtE transition further. By promoting sustainable technological development and advancement policies, policymakers and city planners/managers can ensure a low carbon energy sector and achieve sustainability while effectively managing waste.

Implications for Achieving SDGs

The results of this study have important ramifications for advancing the adoption of WtE technology which will help the achievement of various United Nations' SDGs. This study's global ranking of challenges includes the 'need for well-developed planning and incentivized policy-making,' 'Ineffectiveness in waste segregation at the source,' and 'high costs for installation, maintenance, and infrastructure development'. Tackling these challenges is of utmost importance to foster sustainable waste management practices, mitigate greenhouse gas (GHG) emissions during energy generation and lower the cost of energy generation which can help in achieving SDG 7 (affordable and clean energy). The 'need for well-developed planning and incentivized policymaking' can contribute to achieving several SDGs, such as SDG 9 (Industry, innovation, and infrastructure), SDG 11 (Sustainable cities and communities) and SDG 17 (Partnership for the goals). By promoting collaboration and partnerships throughout the WtE projects, policymakers can facilitate sustainable economic, social, and environmental development. Similarly, "Ineffectiveness in waste segregation at the source (OC1)" can contribute to achieving SDG 6 (Clean water and sanitation) and SDG 13 (Climate action) by promoting proper waste management practices, recycling and reuse of waste to reduce greenhouse gas emissions. By addressing the identified challenges, policymakers can create operational strategies to achieve the SDGs and contribute to creating a sustainable future for all.

Conclusion

Rapid population growth has created enormous challenges for waste management and the demand for green energy supplies to support clean urbanization especially in developing nations like Bangladesh. Implementing WtE conversion using municipal solid waste can be a promising solution as it addresses the energy deficit and promotes clean and sustainable waste management practices, providing benefits such as reducing greenhouse gas emissions, decreasing waste volume in landfills and responding to several SDGs.

However, implementing WtE conversion in emerging economies like Bangladesh poses several operational, technical, managerial, and economic challenges that require special attention. The methodology employed for this study encompasses a comprehensive literature review, expert consultations and the application of the Bayesian BWM framework to evaluate the challenges. The study findings indicate that the most prominent cluster of challenges is related to managerial aspects, followed by operational, technical, and economic challenges.

The study's contributions are substantial and far-reaching. This study emphasizes the imperative for a broad and transformative strategy to effectively confront the multifaceted challenges inherent in implementing WtE initiatives particularly in the context of emerging economies like Bangladesh. This proposed framework empowers energy sector decision-makers in efficiently prioritizing challenges for a successful WtE transition. The study's focus on WtE's role in meeting escalating energy demands amid growing waste generation holds paramount importance. In practical terms, the framework assists policy makers and stakeholders in emerging economies in navigating the challenges and transitioning towards a sustainable future. Policymakers are urged to proactively design and implement

comprehensive, incentive driven plans that go beyond regulatory frameworks to support WtE projects. This involves considering innovative financing mechanisms, incentivized partnerships and long-term sustainability commitments. Simultaneously, industry stakeholders are encouraged to adopt a holistic approach by strategically investing in managerial training programs and research and development initiatives that foster technological innovation. Collaborative partnerships should extend beyond sectoral boundaries involving academia, civil society and international organizations to create a synergistic platform for addressing the diverse operational, technical, and economic challenges. The outcomes of this study are also expected to facilitate the achievement of various key SDGs such as affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11) and climate action (SDG 13) which can help us to stride towards a sustainable future.

This study has some limitations which can be overcome in future research attempts. For instance, future research can broaden its scope by including various other economic perspectives not just restricting the context to emerging economies. Additionally, weighing expert opinions in accordance with their level of knowledge and pertinent experience might improve the precision of the findings. Additionally, this study relied on feedback from a limited number of experts due to the embryonic stage of WtE conversion in Bangladesh. Future researchers can gather more expert opinions to obtain more comprehensive and bias-free results. Another limitation of this study is that it does not show how the challenges influence each other. Future studies can explore this issue by using techniques like Interpretive Structural Modeling (ISM) or Total Interpretive Structural Modeling (TISM). They can also statistically validate those relationships by using methods like partial least squares with structural equation modeling (PLS-SEM).

References

- Adeleke, O., Akinlabi, S., Jen, T. C., & Dunmade, I. (2021). Towards sustainability in municipal solid waste management in South Africa: A survey of challenges and prospects. *Transactions of the Royal Society of South Africa*, 76(1), 53–66.
- Adenuga, O.T., Mpofu, K., & Modise, K. R. (2020). An approach for enhancing optimal resource recovery from different classes of waste in South Africa: Selection of appropriate waste to energy technology. *Sustainable Futures*, 2, 100033.
- Adeoye-Olatunde, O. A., & Olenik, N. L. (2021). Research and scholarly methods: Semi-structured interviews. *Journal of the American college of Clinical Pharmacy*, 4(10), 1358–1367.
- Adnan, A., Mahmud, S., Uddin, M., Modi, A., Ehsan, M.M., & Salehin, S. (2021). Energy, Exergy, Exergoeconomic, and environmental (4E) analyses of thermal power plants for municipal solid waste to energy application in Bangladesh. *Waste Management*, 134, 136–148.

- Agbefe, L.E., Lawson, E.T., & Yirenya-Tawiah, D. (2019). Awareness on waste segregation at source and willingness to pay for collection service in selected markets in Ga West Municipality, Accra, Ghana. *Journal of Material Cycles and Waste Management*, 21(4),905–914.
- Ahmed, S., Hossian, A., & Alam, F. (2022). *Energy security evaluation through solid waste management in Dhaka city, Bangladesh*. AIP conference proceedings, American Institute of Physics.
- Akkalatham, W., Taghipour, A., Yongsiri, P., & Ali, S. M. (2023). *Circular economy in materials to decarbonize mobility*. Renewable energy in circular economy (pp. 89–112). Cham: Springer International Publishing.
- Akter, H., Howlader, H.O.R., Nakadomari, A., Islam, M.R., Saber, A.Y., & Senjyu, T. (2022). A short assessment of renewable energy for optimal sizing of 100% renewable energy based microgrids in remote islands of developing countries: A case study in Bangladesh. *Energies*, 15(3), 1084.
- Ali, S. M., Hoq, S. N., Bari, A. M., Kabir, G., & Paul, S. K. (2022). Evaluating factors contributing to the failure of information system in the banking industry. *PLoS One*, 17(3), e0265674.
- Ali, J., Rasheed, T., Afreen, M., Anwar, M., Nawaz, Z., Anwar, H., & Rizwan, K. (2020). Modalities for conversion of waste to energy — challenges and perspectives, *Science of the Total Environment*, 727, 138610.
- Awasthi, S. K., Sarsaiya, S., Kumar, V., Chaturvedi, P., Sindhu, R., Binod, P. Awasthi, M.K. (2022). Processing of municipal solid waste resources for a circular economy in China: An overview. *Fuel*, 317, 123478.
- Bag, S., Mondal, N. K., & Dubey, R. S. (2016). Modeling barriers of solid waste to energy practices: AN INDIAN perspective. *Global Journal of Environmental Science and Management*, 2(1), 39–48.
- Barma, M., Biniyamin, H. K., Modibbo, U. M., & Gaya, H.M.A. (2022a). Mathematical model for the optimization of municipal solid waste management. *Frontiers in Sustainability*, 3, 880409.
- Barma, M., & Modibbo, U.M. (2022b). Multiobjective mathematical optimization model for municipal solid waste management with economic analysis of reuse/recycling recovered waste materials. *Journal of Computational and Cognitive Engineering*, 1(3), 122–137.

- Bosmans, A., Vanderreydt, I., Geysen, D., & Helsen, L. (2013). The crucial role of waste-to-energy technologies in enhanced landfill mining: A technology review, *Journal of Cleaner Production*, 55, 10–23.
- Bui, T., Tseng, J., Tseng, M., & Lim, M.K. (2022). Opportunities and challenges for solid waste reuse and recycling in emerging economies: A hybrid analysis. *Resources, Conservation and Recycling*, 177, 105968.
- Chand Malav, L., Yadav, K. K., Gupta, N., Kumar, S., Sharma, G. K., Krishnan, S., & Bach, Q.V. (2020). A review on municipal solid waste as a renewable source for waste-to-energy project in India: Current practices, challenges, and future opportunities. *Journal of Cleaner Production*, 277, 123227.
- Cucchiella, F., D'Adamo, I., & Gastaldi, M. (2017). Sustainable waste management: Waste to energy plant as an alternative to landfill, *Energy Conversion and Management*, 131, 18–31.
- Cui, C., Liu, Y., Xia, B., Jiang, X., & Skitmore, M. (2020). Overview of public-private partnerships in the waste-to-energy incineration industry in China: Status, opportunities, and challenges. *Energy Strategy Reviews*, 32, 100584.
- Damayanti, P., Moersidik, S. S., & Haryanto, J.T. (2021). Waste to energy in sunter, jakarta, Indonesia: Plans and challenges. IOP conference series. *Earth and Environmental Science*, 940(1), 012033.
- Dastjerdi, B., Strezov, V., Rajaeifar, M.A., Kumar, R., & Behnia, M. (2021). A systematic review on life cycle assessment of different waste to energy valorization technologies. *Journal of Cleaner Production*, 290, 125747.
- Debnath, B., Bari, A.M., de Jesus Pacheco, D.A., & Karmaker, C. L. (2023a). An integrated Best–Worst Method and Interpretive Structural Modeling approach for assessing the barriers to circular economy implementation. *Decision Analytics Journal*, 7, 100250.
- Debnath, B., Shakur, M. S., Bari, A.M., & Karmaker, C. L. (2022). A Bayesian Best-Worst approach for assessing the critical success factors in sustainable lean manufacturing. *Decision Analytics Journal*, 100157.
- Debnath, B., Shakur, M.S., Bari, A. M., Saha, J., Porna, W.A., Mishu, M. J., & Rahman, M.A. (2023b). Assessing the critical success factors for implementing industry 4.0 in the pharmaceutical industry: Implications for supply chain sustainability in emerging economies. *PLoS One*, 18(6), e0287149.
- Debnath, B., Shakur, M.S., Siraj, M.T., Bari, A.M., & Islam, A.R.M.T. (2023c). Analyzing the factors influencing the wind energy adoption in Bangladesh: A pathway to sustainability for emerging economies. *Energy Strategy Reviews*, 50, 101265.

- Debnath, B., Siraj, M.T., Rashid, K.H.O., Bari, A.M., Karmaker, C. L., & Al Aziz, R. (2023d). Analyzing the critical success factors to implement green supply chain management in the apparel manufacturing industry: Implications for sustainable development goals in the emerging economies. *Sustainable Manufacturing and Service Economics*, 2, 100013.
- Esmaeilian, B., Wang, B., Lewis, K., Duarte, F., Ratti, C., & Behdad, S. (2018). The future of waste management in smart and sustainable cities: A review and concept paper. *Waste Management*, 81, 177–195.
- Fard, M. B., Hamedani, A., Ebadi, M., Hamidi, D., Motlaghzadeh, K., Emarati, M., & Mckay, G. (2023). Sustainable waste-to-energy plant site selection by a hybrid method of geographic information system and evidential reasoning: A case study Guilan province. *Process Safety and Environmental Protection*, 176, 316–331.
- Finance Division (2022). *Bangladesh economic review 2022*. Retrieved from <https://mof.portal.gov.bd/site/page/28ba57f5-59ff-4426-970a-bf014242179e/Bangladesh-Economic-Review-2022>. (Accessed 14 May 2023).
- Fuss, M., De Vasconcelos Barros, R.T., & Pogonietz, W. (2018). Designing a framework for municipal solid waste management towards sustainability in emerging economy countries - an application to a case study in Belo Horizonte (Brazil). *Journal of Cleaner Production*, 178, 655–664.