Energy Recovery Technology and Recycling Quantity Estimation of Urban Solid Waste in Dhaka.

Lappeenranta–Lahti University of Technology LUT

LUT School of Energy System

Bachelor of Energy Technology

2026

Sabiha Shabnam

Examiners: Ayesha Sadiqa, Post-doctoral Researcher (Energy Technology)

Changping Zhang, Professor, Department Head

Abstract

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Dhaka generates 8,800 tonnes of municipal solid waste daily, yet less than 40% is formally collected and almost none is converted to energy. This study quantifies the energy recovery potential of Dhaka's waste stream and evaluates three waste-to-energy (WtE) technologies: incineration, anaerobic digestion (AD), and gasification. Using waste composition data (65% organic, 12% plastics, 8% paper) and a lower heating value of 6–8 MJ/kg, the gross energy potential is calculated at 17,111 MWh/day. Scenario analysis shows that under fully segregated, hybrid AD-gasification systems, 15–20% of Dhaka's daily electricity demand could be met – compared to only 5–7% under current practices. Multi-criteria decision analysis ranks anaerobic digestion highest due to its suitability for organic waste, lower emissions, and greater social acceptance. However, the municipal budget for waste management is less than 1%, a critical policy barrier. The study concludes that a hybrid AD-gasification strategy is the most sustainable pathway, requiring investment in segregation infrastructure and policy integration.

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Abbreviations

DFMA Design for Manufacturing and Assembly

DNCC Dhaka North City Corporation

DSCC Dhaka South City Corporation

HTC Hydrothermal Carbonisation

ISSN International Standard Serial Number

LHV Lower Heating Value

LUT Lappeenranta University of Technology

MCDA Multi-criteria decision analysis

MJ Megajoules

MSW Municipal Solid Waste

MWh Megawatt-hour

NGOs Non-governmental organizations

WtE Waste-to-energy

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Declarations

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1. AI tool name Copilot
    a. Purpose of use: Ideation and drafting tasks.
    b. Explanation of the use of the tool: I used Copilot for idea generation and drafting my task in some cases.

NOTE! Record all the AI tools you have used in the same way.

Responsibility

Sabiha Shabnam, takes full responsibility for the content of this thesis and has reviewed and edited the content generated by the possible use of AI tools.

1. Introduction

Managing municipal solid waste is a serious challenge for fast-growing cities, especially in developing countries. In Dhaka, the capital of Bangladesh, thousands of tonnes of waste are generated every day, but most of it is not used for energy. This thesis will identify and evaluate ways to recover energy from Dhaka's municipal solid waste, compare how effective different technologies are, and assess their impact on sustainability. Studying municipal waste management is important because renewable energy is a key environmental issue today. Overall, waste-to-energy methods can help reduce landfill use, lower greenhouse gas emissions, and support sustainable urban energy systems.

Figure 1: An open waste dumping station at Dhaka (image source- local newspaper)

Research has shown that technologies such as incineration, anaerobic digestion, and gasification can convert waste into usable energy (Aguilar-Virgen & Taboada-González, 2025; Abedin et al., 2025). The findings from this research also indicate that energy recovery helps produce electricity, heat, and biofuels. In countries with advanced waste management, these methods are now incorporated into national energy plans, demonstrating how waste can be a valuable resource rather than a problem.

Figure 2: A waste dumping and sorting station at Dhaka (Image source - a local English daily newspaper)

Most research so far looks at developed countries that already have strong waste collection and sorting systems (Soni et al., 2025). In contrast, cities like Dhaka, which have diverse waste types, collection methods, and infrastructure, have not received as much attention. Earlier studies have not clearly shown whether certain waste-to-energy technologies would work in these places or measured how much energy could actually be recovered from local waste. This gap indicates that Dhaka's municipal solid waste requires a more focused study.

This thesis will estimate how much energy can be recovered from Dhaka's municipal solid waste and identify which technologies would work best there. The main research question is to find waste-to-energy solutions for Dhaka that are practical, efficient, and suited to local needs

Key research questions include:

1) What is the energy potential of Dhaka's current waste stream?

2) Which technologies are most feasible given the city's infrastructure and socio-economic conditions?

2. Literature review

This literature review offers a comprehensive synthesis of existing research on municipal solid waste management and energy recovery technologies. The review contextualizes the current study within both global and regional frameworks, identifies the strengths and limitations of various methodologies, and delineates research gaps that support a focused investigation of municipal solid waste in Dhaka.

2.1 Global Perspectives on Municipal Solid Waste Management

Managing municipal solid waste is a major global challenge because of rapid urbanization, industrial growth, and rising populations. The World Bank estimates that by 2050, the world will produce 3.4 billion tonnes of waste each year, underscoring the importance of sustainable management.

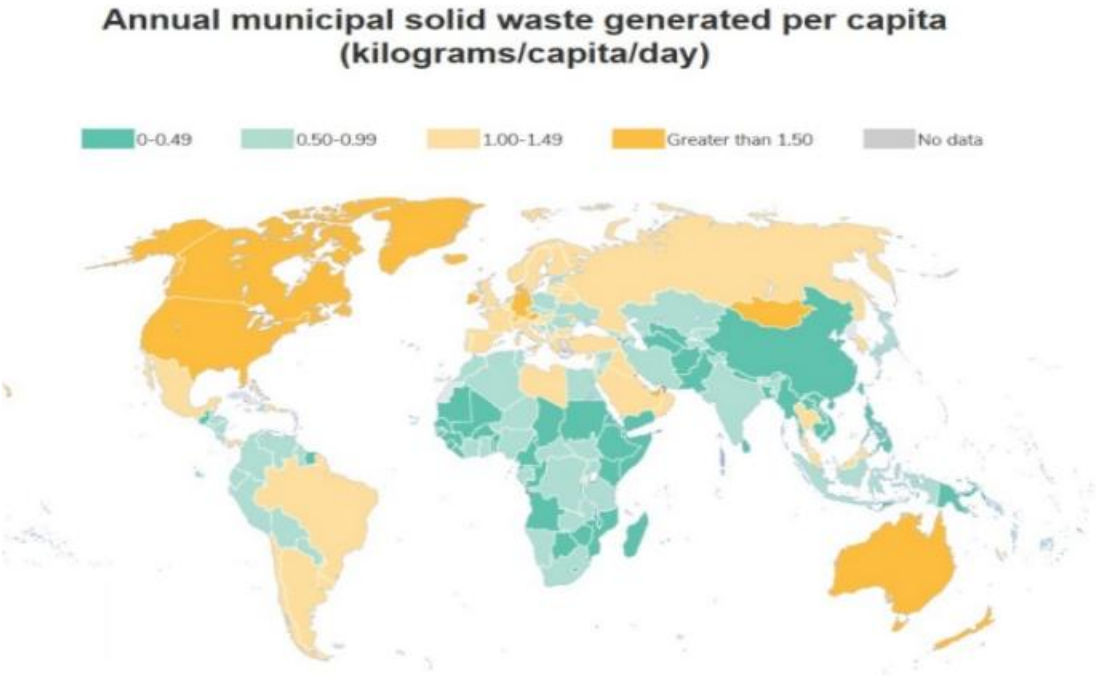

Figure 3: Solid waste generation per capita (Kilograms/capita/day); data source – the world bank

Developed countries such as Germany, Sweden and Japan have implemented advanced systems that combine recycling, energy recovery, and circular economy principles. In contrast, many developing nations such as Bangladesh, Pakistan and Kenya continue to face inadequate infrastructure and weak policy enforcement. Effective waste management is increasingly recognized as both an environmental necessity and an economic opportunity,

particularly through resource recovery and energy generation. European nations, for instance, have integrated waste-to-energy technologies into national energy strategies, thereby reducing landfill dependency and supporting renewable energy targets (Kafle et al., 2025). Conversely, countries in Asia and Africa encounter persistent challenges, including poor waste segregation, limited financial resources, and weak institutional frameworks. This regional disparity underscores the need for context-specific approaches rather than universal solutions. Researchers emphasize that global cooperation and knowledge transfer are critical to bridging these gaps and advancing sustainable waste management practices (Assunção et al., 2023 and WtERT, 2024). Furthermore, the environmental consequences of inadequate waste handling, such as greenhouse gas emissions and water contamination, underscore the urgency of addressing this global issue.

Figure 4: A waste management station at Baguio city in Philippines Source: Pixabay (copyright-free image)

2.2 Energy Recovery Technologies: Incineration, Anaerobic Digestion, and Gasification

Waste-to-energy (WtE) technologies are extensively studied as pathways for converting municipal solid waste into electricity, heat, and biofuels. Incineration is the most established method worldwide, especially in Europe and Japan, where it is integrated into national energy strategies. This process involves direct combustion of waste at high temperatures to produce electricity and heat, but it also generates emissions and ash that require careful management. Studies indicate that incineration achieves energy efficiencies of 20–25%, with advanced combined heat and power plants reaching higher values. In contrast, anaerobic digestion is particularly effective for organic waste fractions, which are prevalent in cities such as Dhaka (Hasan et al., 2024). This biological process decomposes organic matter in the absence of oxygen, producing biogas that can be converted into electricity or upgraded to biomethane. Research demonstrates that anaerobic digestion systems achieve conversion efficiencies of 30-40% and produce nutrient-rich digestate suitable for use as fertilizer. Gasification is a more advanced thermal technology that converts waste into syngas through partial oxidation at high temperatures. The resulting syngas can be use to generate electricity or serve as a feedstock for liquid fuels and chemicals. Compared to incineration, gasification produces fewer emissions and offers greater flexibility in energy recovery, although it requires more sophisticated infrastructure and higher capital investment. Studies report gasification efficiencies of 25-30%, depending on waste composition and plant design (Alwossabee, 2024 Kumar et al., 2025). A comparative analysis indicates that no single technology is universally optimal; the choice depends on local waste characteristics, infrastructure capacity, and socio-economic conditions (Aguilar-Virgen et al., 2025). In Dhaka, where organic waste predominates but plastics and paper also contribute significantly to calorific value, a hybrid approach combining anaerobic digestion and gasification may offer the most balanced solution (Kalange et al., 2025).

Figure 5: A waste management and processing site in Iran

2.3 Waste-to-Energy in Developing Countries

The adoption of waste-to-energy (WtE) technologies in developing countries is influenced by infrastructure limitations, policy deficiencies, and socio-economic factors. Rapid urbanization in cities throughout Asia and Africa has resulted in increased waste generation, while collection and segregation systems remain insufficient. In many South Asian cities, for instance, less than half of municipal solid waste is formally collected, leaving significant quantities unmanaged and exacerbating environmental degradation (Hoornweg & Bhada-Tata, 2012: Alam, R. & Chowdhury, 2025; Islam, M.S., 2024). These infrastructural shortcomings hinder the implementation of advanced WtE technologies, which require consistent waste streams and reliable segregation. Policy frameworks are often underdeveloped, with limited enforcement of waste management regulations and inadequate incentives for private sector participation. Research indicates that, in the absence of robust governance, WtE projects are at risk of becoming unsustainable or failing entirely (Guerrero et al., 2013).

Financial barriers further impede the adoption of WtE technologies, as these facilities require substantial capital investment and ongoing operational expenditures. Developing countries

like Bangladesh, India, Pakistan, Nepal, and Kenya frequently rely on donor funding or international partnerships to launch pilot projects; however, scaling these initiatives into citywide systems remains challenging. Public perception is also a significant factor, with communities often opposing incineration projects due to concerns regarding air pollution and health risks. Anaerobic digestion tends to be more socially acceptable, especially in areas with high proportions of organic waste, yet it still necessitates investment in waste segregation infrastructure. Although gasification offers potential benefits, it is seldom implemented in developing countries because of its technological complexity and high costs (Kafle et al., 2025).

Although several barriers exist, the literature identifies substantial opportunities. Increasing energy demand in developing countries provides a compelling rationale for investigating waste-to-energy (WtE) as a renewable energy source (Soni et al., 2025). The prevalence of organic waste in urban areas further underscores the relevance of biological treatment methods. Evidence from case studies in India and Bangladesh demonstrates that small-scale anaerobic digestion plants can deliver localized energy solutions; however, successful scaling depends on coordinated policy support (Assunção et al., 2023). Scholars contend that incorporating WtE into comprehensive urban sustainability strategies may simultaneously address waste management and energy security challenges (Vukovic & Makogon, 2022; Obinna et al., 2025).

International collaboration is frequently identified as a key factor for successful WtE implementation. An example of international collaboration that successfully advanced WtE implementation is the Singapore-Japan partnership on the Tuas South Incineration Plant. The transfer of knowledge from countries with established WtE systems enables developing nations to avoid common pitfalls and adapt technologies to local contexts. Policy reforms, including subsidies for renewable energy and stricter landfill regulations, are recognized as essential enablers. The literature indicates that WtE adoption in developing countries extends beyond technical challenges and encompasses governance and policy considerations. In the absence of robust institutional frameworks, adequate infrastructure investment, and active community engagement, WtE projects are unlikely to achieve sustained success (World Bank, 2025; Roy et al., 2024).

In summary, although developing countries encounter significant barriers to WtE adoption, the potential benefits for energy recovery, environmental protection, and urban sustainability are considerable. Effective implementation depends on designing context-specific solutions that balance technical feasibility with socio-economic realities. This approach necessitates investment in infrastructure, policy innovation, and international cooperation. As waste volumes increase, the urgency of addressing these challenges intensifies, positioning WtE as a critical area of research and practice for the developing world (Das & Mitra, 2025).

2.4 Case Studies from South Asia and Bangladesh

WtE initiatives have gained increasing attention in South Asia, primarily due to rapid urbanization and rising energy demand. In India, several pilot projects have been implemented in metropolitan areas such as Delhi and Bangalore, where incineration and biomethanation plants have been tested for municipal solid waste management. These projects demonstrate both the potential benefits and the challenges associated with WtE adoption, particularly as inconsistent waste segregation and high moisture content frequently reduce operational efficiency (Sharholy et al., 2008; Sharholy et al., 2008). Bangladesh encounters comparable obstacles, with Dhaka producing approximately 7,500 tonnes of waste daily, less than half of which is formally collected. The predominance of organic waste in Dhaka's waste stream suggests that anaerobic digestion could be a viable solution; however, large-scale implementation remains constrained by infrastructural and financial limitations (Alam & Ahmade, 2013).

Numerous small-scale anaerobic digestion projects have been implemented in Bangladesh, frequently with support from international donors and non-governmental organizations. These initiatives demonstrate that biogas production from organic waste can offer localized energy solutions, particularly in peri-urban and rural settings. However, scaling such projects to the municipal level requires coordinated policy support and investment in waste-segregation infrastructure (Kabir et al., 2024). Case studies indicate that public perception significantly influences project outcomes, as communities often oppose incineration projects due to concerns regarding air pollution. Conversely, biogas projects generally receive greater acceptance, particularly when associated with agricultural benefits such as fertilizer production (The Business Standard, 2024).

Regional comparisons indicate that, while India has advanced further in piloting diverse waste-to-energy (WtE) technologies, Bangladesh remains in the early stages of adoption. The absence of consistent data on waste composition and calorific value complicates effective planning and implementation. Nevertheless, Dhaka's escalating waste management challenges and increasing energy demand provide strong incentives to pursue WtE solutions. Researchers suggest that hybrid approaches, integrating anaerobic digestion for organic fractions with gasification for plastics and paper, may offer a balanced strategy for Bangladesh (Rahman et al., 2019).

2.5 Environmental and Socio-Economic Impacts of Waste-to-Energy Systems

Waste-to-energy (WtE) systems are increasingly recognized for their dual function in addressing waste management challenges and supporting renewable energy generation. These systems reduce dependence on landfills, which are significant sources of methane emissions, a potent greenhouse gas. Although incineration effectively reduces waste volume, it raises concerns about air pollution and emissions of toxic substances, including dioxins and heavy metals (Kafle et al., 2025). In contrast, anaerobic digestion is regarded as more environmentally sustainable, as it produces biogas with lower emissions and generates digestate suitable for use as fertilizer. Gasification provides cleaner energy recovery than traditional incineration; however, its technological complexity restricts widespread implementation in developing regions (Assunção et al., 2023; Singh & Patel, 2024).

From a socio-economic perspective, WtE systems generate employment opportunities in waste collection, segregation, and plant operation. These systems also enhance energy security by diversifying the energy portfolio and reducing reliance on fossil fuels. Nevertheless, substantial capital investment and operational costs present significant obstacles, particularly in low-income countries (Guerrero et al., 2013). Public perception is also a critical consideration, as communities frequently oppose incineration projects due to health concerns, whereas biogas initiatives generally receive greater acceptance because of their agricultural benefits. The literature indicates that successful WtE projects depend on robust policy frameworks, financial incentives, and active community engagement to achieve long-term sustainability (Hoornweg & Bhada-Tata, 2012; Khan et al., 2025).

The literature emphasizes that WtE systems must balance environmental performance with socio-economic viability. Although these systems reduce landfill dependency and generate renewable energy, their effectiveness relies on context-specific strategies that address infrastructure, governance, and public acceptance. In cities such as Dhaka, where organic waste is prevalent, anaerobic digestion offers both environmental and socio-economic benefits; however, successful scaling necessitates coordinated policy support and targeted investment (Shahriar et al., 2025).

2.6 Research Gaps and the Need for Context-Specific Studies

Despite extensive global research on WtE technologies, significant gaps remain in understanding their applicability in developing countries. Much of the existing literature focuses on developed nations, where infrastructure, governance, and financial resources are more robust. This creates a knowledge imbalance, as findings from Europe or North America cannot always be directly transferred to contexts such as Dhaka. Studies often overlook the challenges of inconsistent waste collection, high organic fractions, and limited segregation practices that characterize many cities in South Asia. Furthermore, there is limited empirical data on the calorific value and composition of municipal solid waste in Bangladesh, making accurate assessments of its energy potential difficult (Rahman & Sultana, 2024).

Policy-related gaps persist, as limited research investigates the influence of governance structures, regulatory enforcement, and public awareness on waste-to-energy (WtE) adoption in developing countries. Socio-economic factors, such as affordability, community acceptance, and employment generation, remain insufficiently addressed in technical assessments. Additionally, there is a lack of comparative evaluation of hybrid approaches, including integrating anaerobic digestion with gasification, which may be particularly suitable for organic-rich waste streams with substantial combustible fractions. The absence of long-term monitoring data from pilot projects in Bangladesh further restricts a comprehensive understanding of operational sustainability (Ahmed et al., 2025).

In summary, the literature underscores the necessity for context-specific studies that integrate technical, environmental, and socio-economic dimensions. In the case of Dhaka, this requires developing tailored models that account for local waste composition, infrastructure constraints, and policy frameworks. Addressing these gaps will enhance academic

understanding and offer actionable guidance for policymakers and stakeholders pursuing sustainable waste-to-energy solutions.

3. Methodology

This thesis began with a comprehensive literature review to understand the global and local context of WtE technologies. The review helped identify the strengths and weaknesses of different approaches and highlighted the specific challenges Dhaka faces in managing municipal solid waste. Building on this foundation, the study focuses on estimating the energy recovery potential of Dhaka's waste stream using quantitative methods. It also evaluates the suitability of incineration, anaerobic digestion, and gasification technologies within the city's unique context. The research design emphasizes both technical and socio-economic dimensions, ensuring that the analysis goes beyond energy calculations alone. I am motivated by combining secondary data with comparative technology assessment, the study aims to provide a balanced view of opportunities and limitations. Ultimately, this study seeks to answer the following research question: "How can waste-to-energy (WtE) technologies contribute to transforming Dhaka's municipal solid waste into a sustainable energy resource?

This study is undertaken as part of a bachelor's study, with the goal of contributing to both academic knowledge and practical solutions for Dhaka's waste management challenges. The motivation originated from the growing energy demand in Bangladesh and the mounting pressure on urban waste systems. Dhaka generates thousands of tonnes of waste daily, much of which is poorly managed and ends up in landfills, creating environmental and health risks. By exploring WtE technologies, this thesis aims to show how waste can be reframed as a renewable energy source rather than a liability. This study also seeks to highlight the importance of integrating energy recovery into broader urban sustainability strategies.

The primary objective of this study is to evaluate the energy recovery potential of Dhaka's municipal solid waste and assess the suitability of different waste-to-energy technologies, including incineration, anaerobic digestion, and gasification. The study also aims to analyze the environmental, economic, and socio-technical implications of implementing WtE systems in Dhaka.

Accordingly, the central research question of this thesis is: “How can waste-to-energy (WtE) technologies contribute to transforming Dhaka’s municipal solid waste into a sustainable source of energy?”

The study is conducted through document review and secondary data collection, ensuring the analysis is grounded in reliable sources. Waste generation statistics are obtained from Dhaka North and South City Corporations (Dihan et al., 2024; Fahad et al., 2026), while composition data and calorific values are drawn from published studies and government reports (Islam, 2025; Hossain & Akter, 2025). International case studies (Kafle et al., 2025; Assunção et al., 2023) provide benchmarks for energy conversion efficiencies, allowing comparisons with Dhaka’s context. The analytical framework applies the Lower Heating Value (LHV) method to calculate the energy content of different waste fractions. Scenario analysis is also applied, considering best-case and worst-case conditions to capture the range of possible outcomes. This structured approach helps me ensure that findings are comprehensive, transparent, and relevant to both academic inquiry and practical application.

3.1 Research design

Quantitative and analytical research design is employed to estimate the energy recovery potential of Dhaka’s MSW. The methodology integrates secondary data analysis (data from the secondary sources) with a comparative assessment of WtE technologies. This approach facilitates evaluation of both the quantity of recoverable energy and the suitability of various WtE technologies within the context of Dhaka.

3.1.1 Data Collection

Waste Quantities and Composition: Secondary data on daily MSW generation for Dhaka City is obtained from published reports by Dhaka North City Corporation (DNCC), Dhaka South City Corporation (DSCC), and peer reviewed literature (Dihan et al., 2024; Fahad et al., 2026). The total waste mass is 8,800 tonnes/day. The detailed physical composition, based on recent characterization studies (Islam, 2025; Rahul et al., 2026), is: organic/food waste (65%), plastics (12%), paper and cardboard (8%), textiles (3%), rubber/leather (2%), metals (2%), glass (1%), and inerts/dirt (7%).

Calorific Values: The energy content (Lower Heating Value, LHV) of each waste fraction is taken from published studies on Dhaka's waste (Islam, 2025; Hossain & Akter, 2025). The average LHV for mixed MSW is 6–8 MJ/kg. Specific values (kJ/kg) are: food 4,652; plastic 32,564; paper 16,747; rubber 23,260; textile 17,445; ferrous 698; glass 140; dirt 6,978; leather 17,445.

Technological Parameters: Key performance indicators for each WtE technology are extracted from recent literature:

- Incineration (INC): Electrical efficiency 20–25%, high sensitivity to moisture (Kafle et al., 2025; Billah et al., 2024).

- Anaerobic Digestion (AD): Electrical efficiency 30–40%, optimal for organic waste (Makky et al., 2025; Hasan et al., 2024).

- Gasification (GAS): Electrical efficiency 25–30%, suited for plastics and paper (Alwossabee, 2024; Kumar et al., 2025).

Policy Framework Data: National and local policy documents are reviewed, including Bangladesh's Renewable Energy Policy 2025 (Government of Bangladesh, Ministry of Power, Energy and Mineral Resources, 2025), the 8th Five Year Plan (2020–2025)(Planning Commission, Government of Bangladesh, 2020), SREDA action plans, and municipal budget reports (Jumman Sani, 2025).

3.2 Analytical Framework for Energy Potential

The overall analytical framework of the study is illustrated below, which outlines the sequential process of data acquisition, waste characterization, energy estimation, and technology evaluation.

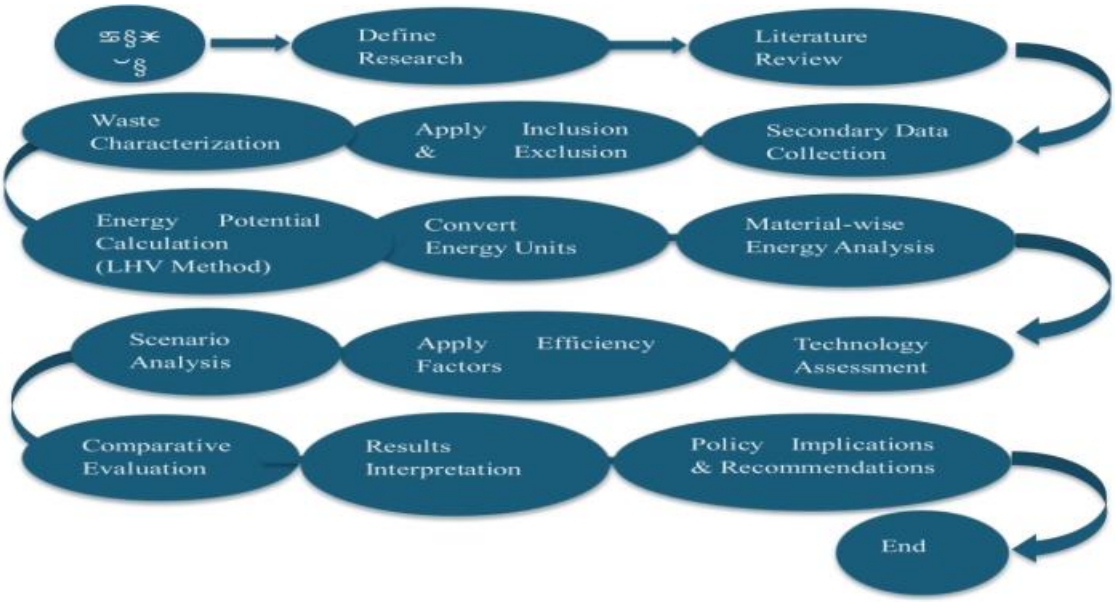

Figure 6: Analytical Framework

The gross theoretical energy potential of Dhaka's MSW is calculated using the Lower Heating Value (LHV) method:

$E = \Sigma (W_i \times CV_i)$

where:

- E = total daily energy potential (MJ/day)
- W_i = mass of waste fraction i (kg/day)
- CV_i = calorific value of fraction i (MJ/kg)

The calculation is performed for each waste fraction using the composition and CV (Calorific Values) data from Section 3.1.1. The total daily energy potential is then converted to MWh/day using the conversion factor 1 MWh = 3.6×10^3 MJ. Net electricity generation is obtained by multiplying the gross energy potential by the system's electrical efficiency (applied in scenario analysis).

3.3 Policy and Institutional Framework Analysis

To assess the feasibility of implementing recommended WtE technologies, a qualitative analysis of existing policy and institutional frameworks in Bangladesh is conducted. The analysis focuses on:

- Regulatory environment: National policies for waste management (Solid Waste Management Rules, 2021), renewable energy targets (Renewable Energy Policy, 2025; 8th Five Year Plan), and environmental clearance procedures.
- Institutional roles: The mandate of the Sustainable and Renewable Energy Development Authority (SREDA), Dhaka North and South City Corporations, and the Department of Environment.
- Budgetary allocation: As reported by Jumman Sani (2025), the municipal budget for waste management services is less than 1% of total expenditure, compared to 10 15% for road maintenance and 15 20% for education and health.
- Enabling policies from peer countries: A brief comparison with India (national WtE policy, tariff support) and Thailand (clean energy incentives) is drawn to identify actionable recommendations for Bangladesh.

4. Result and analysis

This section presents the study's findings regarding the composition of municipal solid waste in Dhaka and its potential for energy recovery. The calorific value of various waste fractions is analyzed, and the efficiency of technologies, including incineration, anaerobic digestion, and gasification, is evaluated.

4.1 Waste Generation and Composition

Dhaka generates approximately 8,800 tonnes of municipal solid waste daily, of which only about 37% is formally collected. Dhaka North City Corporation (DNCC) collects the highest share at 35%. Composition analysis (breaking down Dhaka’s municipal solid waste into its different fractions like organic, plastics, paper, metals, glass, etc.) indicates that organic

matter constitutes nearly 65%, plastics about 12%, paper around 8%, and metals and glass together less than 10% (Rahul et al. 2026). The predominance of organic waste indicates significant potential for biological treatment methods such as anaerobic digestion. Although plastics and paper represent smaller proportions, their high combustibility contributes substantially to the overall calorific value. This composition underscores the necessity for a diversified technological strategy. In the absence of segregation, mixed waste streams diminish processing efficiency and elevate environmental risks. Thus, the composition analysis provides a basis for assessing the most appropriate waste management technologies for Dhaka's specific waste profile.

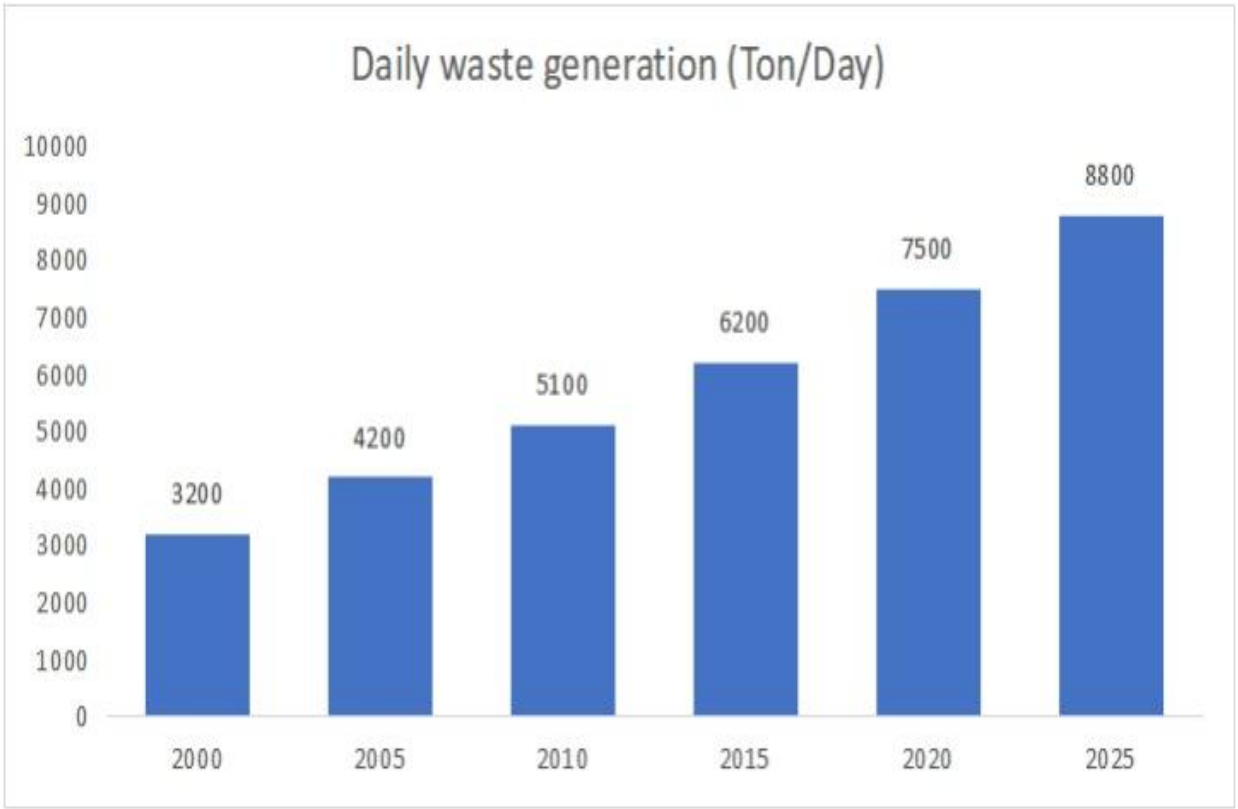

Figure 7: Daily waste generation from 2000 to 2025 (Ton/Daily)

Source: Fahad et al. (2026)

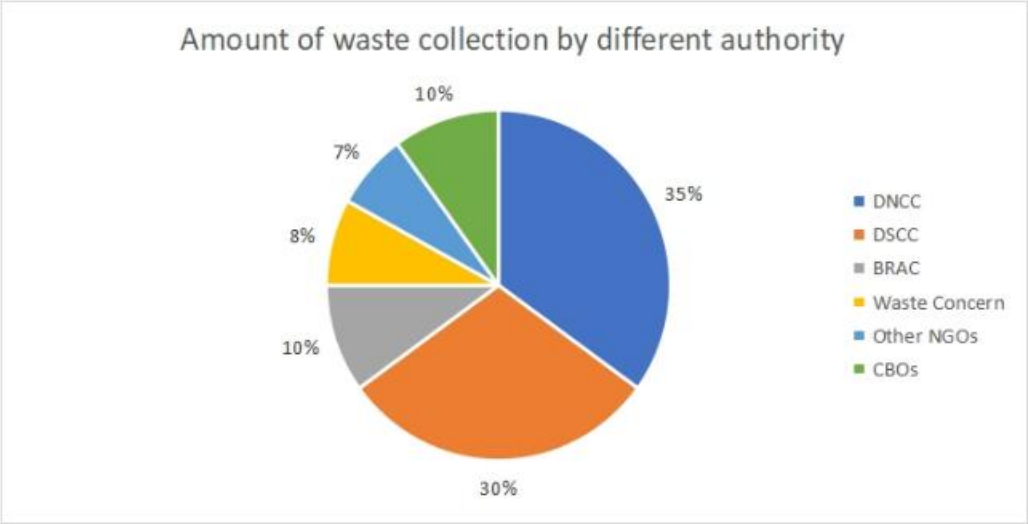

Figure 8: Amount of waste collection by the current authority

Source: Fahad et al. (2026)

4.2 Calorific Value and Energy Potential

The study presents the energy profiles of various material types, measured in kilojoules per kilogram (kJ/kg) and total energy (kJ). There is considerable variation in energy density among the materials, with plastic identified as the most energy-dense at 32,564 kJ/kg, contributing 100,850.7 kJ to the total energy pool (Islam, 2025). In contrast, inert materials such as glass and ferrous metals display the lowest energy values, consistent with their non-combustible properties. Although rubber exhibits a high energy density (23,260 kJ/kg), its total energy contribution is minimal at 302.38 kJ, likely due to its smaller mass in the sample (Hossain & Akter, 2025). In comparison, food and textiles provide substantial total energy despite lower individual energy densities. These findings indicate that polymers and organic fibers, including plastic, textiles, and paper, are the primary contributors to overall energy content (Islam 2025).

This study calculated the calorific value from the amount of waste the Dhaka Municipal is producing.

Calorific value (7 MJ/kg)

E = Waste (kg/Day) x 7MJ/kg

Table 1: Calorific Value Calculation

Year	Waste (kg/day)	Energy Potential (MJ/day)	Energy Potential (MWh/day)
2000	3,200,000	22,400,000	6,222
2005	4,200,000	29,400,000	8,167
2010	5,100,000	35,700,000	9,917
2015	6,200,000	43,400,000	12,056
2020	7,500,000	52,500,000	14,583
2025	8,800,000	61,600,000	17,111

*(Conversion: 1 MWh = 3.6 x 10^3 MJ)

Table 2: Energy analysis by material type (Kilojoules/Kg)

Material types	Energy (Kilojoules/Kg)	Total Energy (Kilojoules)
Food	4652	16537.86
Plastic	32564	100850.7
Paper	16747.2	37463.49
Rubber	23260	302.38
Textile	17445	43752.06
Ferrous	697.8	15.35
Glass	139.56	25.96
Dirt's	6978	1437.47
Leather	17445	3314.55

4.3 Technology-Specific Energy Recovery

Incineration is widely implemented in Europe and Japan, with electricity generation efficiencies typically ranging from 20 to 25 percent. Combined heat and power systems can

achieve higher efficiencies in Dhaka, Bangladesh (Kafle et al 2025). Despite these advantages, incineration presents challenges related to emissions and ash management. Anaerobic digestion is particularly suitable for Dhaka's high organic waste fraction, producing biogas that can be converted into electricity with efficiencies of 30 to 40 percent. Gasification demonstrates significant potential for processing plastics and paper fractions, yielding syngas with efficiencies of 25 to 30 percent and comparatively lower emissions than incineration (Islam, F.A.S. 2025). Data from the different research papers indicate that no single technology can fully address Dhaka's waste management challenges. A hybrid approach that integrates anaerobic digestion for organic waste and gasification for combustible materials may optimize energy recovery.

4.3.1 Technology Specific Energy Recovery Assessment

For each primary technology (incineration, anaerobic digestion, gasification), a detailed sub-analysis is performed:

- Incineration (INC): A sensitivity analysis is conducted to evaluate how increasing MSW moisture content from 70% to 90% reduces the lower heating value and consequently the net power output from 30 MW to as low as 3 MW, based on correlations from Billah et al. (2024).
- Anaerobic Digestion (AD): The conversion of the organic fraction (65% of total waste) to biogas and electricity is modeled using the performance data from the proposed 40 MW AD plant for Dhaka (Makky et al., 2025). A methane yield of 0.35–0.45 m^3/kg volatile solids is assumed.
- Gasification (GAS): Syngas production from plastic and paper fractions (20% of total waste) is modeled. The efficiency of converting syngas to electricity is taken as 25–30% (Kumar et al., 2025). In hybrid configurations, gasification is applied to the non-organic residuals from AD.

4.3.2 Comparative Evaluation Using Multi-Criteria Decision Analysis (MCDA)

An MCDA framework is adopted to compare the overall suitability of INC, AD, and GAS for Dhaka. Four evaluation criteria are defined based on the literature (Chakraborty et al., 2025; Roy et al., 2024):

1. Technical: Energy conversion efficiency, technology maturity, suitability for high moisture waste.
2. Environmental: Net GHG reduction potential, air pollutant emissions (dioxins, acid gases), land use.
3. Economic: Capital and operational costs (USD/ton), net energy revenue, LCOE.
4. Social: Public acceptance, job creation, alignment with existing waste collection systems.

Each technology is scored qualitatively (1–10, where 10 is best) based on evidence from the reviewed literature. Table 2 presents the scoring matrix.

Table 3: MCDA Scoring Matrix for WtE Technologies in Dhaka

Criterion	Incineration (INC)	Anaerobic Digestion (AD)	Gasification (GAS)
Technical (efficiency, maturity)	6	8	7
Environmental (GHG, emissions)	4	9	7
Economic (costs, revenue)	5	7	5
Social (acceptance, jobs)	3	8	6
Total Score	18	32	25

Source: Author's synthesis of Billah et al. (2024), Makky et al. (2025), Alwossabee (2024), and Khan et al. (2025).

The scores are then normalized and used to rank the technologies. The MCDA results inform the policy recommendations.

Two figures are added below for better view.

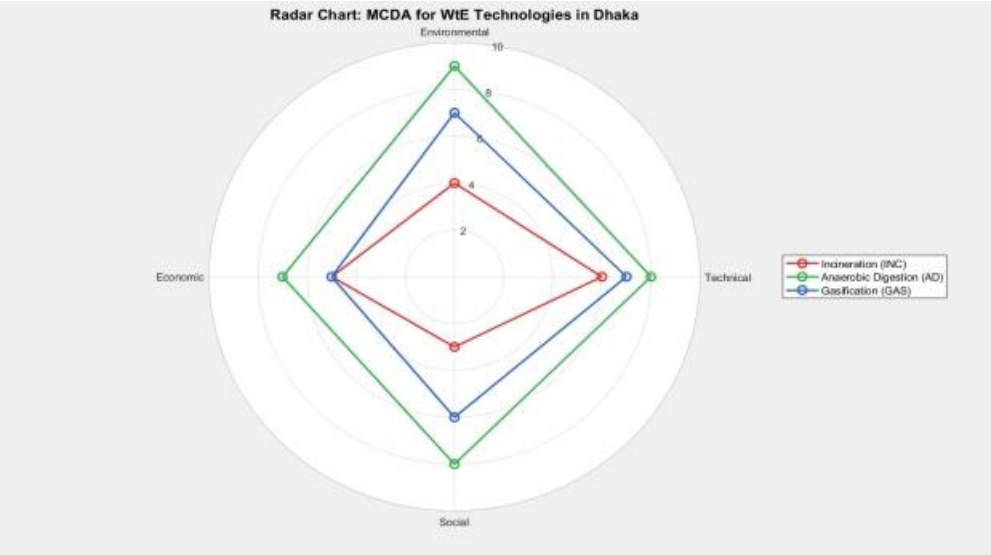

Figure 9: Radar Chart: MCDA for WtE Technologies in Dhaka

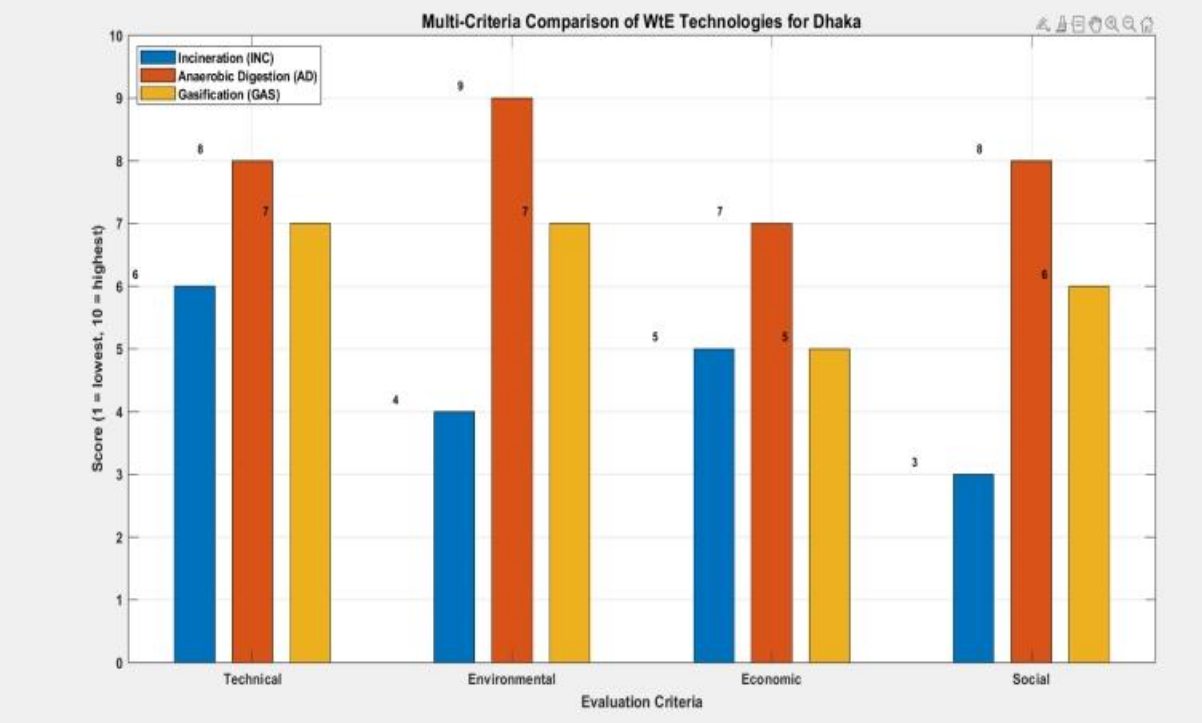

Figure 10: Multi-Criteria Comparison of WtE Technologies for Dhaka

4.4 Scenario Analysis

To address the variability in Dhaka's waste composition, segregation rates, moisture content, and operational conditions, a scenario analysis is conducted based on established frameworks (Siddiqi et al., 2020; Dihan et al., 2024). Ten distinct scenarios are constructed, covering pessimistic, baseline, and optimistic conditions. Table 1 summarizes the scenarios.

Table 4: Scenario Analysis for Energy Recovery from Dhaka's MSW (8,800 tonnes/day)

Scenario	Scenario Name	Waste Composition Focus	Technology	Expected Energy Output Range (MWh/day)
1	Pessimistic 1	Unsorted, high moisture (>70% organics)	Incineration	3,000 – 5,000
2	Pessimistic 2	Unsorted, high moisture	Anaerobic Digestion	2,500 – 4,500
3	Pessimistic 3	Unsorted, high moisture	Gasification	2,000 – 4,000
4	Pessimistic 4	Unsorted, high moisture	Hybrid (AD+GAS)	3,500 – 5,500
5	Baseline 1	Partially sorted (low organic, some plastics/paper)	Incineration	8,000 – 10,000
6	Baseline 2	Partially sorted	Anaerobic Digestion	7,000 – 9,000
7	Baseline 3	Partially sorted	Gasification	6,000 – 8,000
8	Optimistic 1	Fully segregated (organics→AD, plastics/paper→GAS)	Hybrid (AD+GAS)	14,000 – 16,000
9	Optimistic 2	Fully segregated	Hybrid (AD+GAS) – optimized	16,000 – 18,000
10	Optimistic 3	Fully segregated	Hydrothermal Carbonization + Co firing	15,000 – 17,500

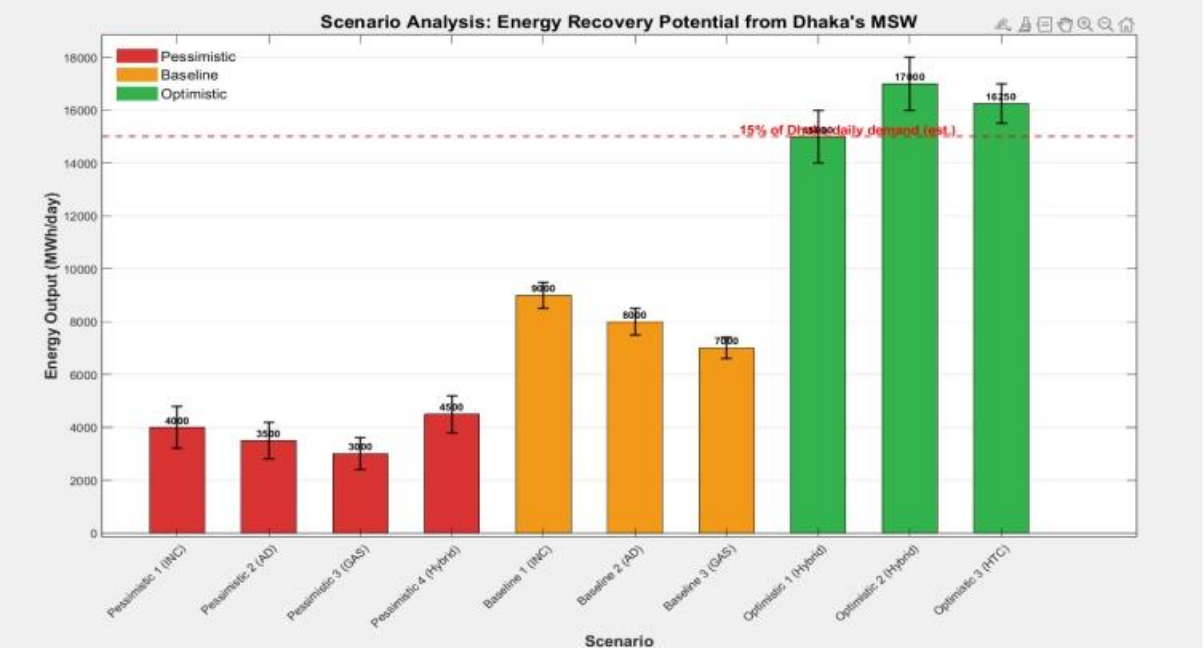

Figure 11: Scenario Analysis: Energy Recovery Potential from Dhaka's MSW

Energy output ranges are the author's calculations based on LHV and technology efficiencies from literature (Kafle et al., 2025; Hasan et al., 2024; Alwossabee, 2024).

Each scenario is modeled using the LHV equation, applying the appropriate moisture adjustment and system efficiency. The results are used to quantify the gap between current practices (scenarios 1–4) and potential optimal performance (scenarios 8–10).

4.5 Comparative Evaluation and Policy Implications

A research paper titled Life Cycle Assessment of Anaerobic Digestion Plant for Treating Municipal Solid Wastes in Dhaka City, Bangladesh shows, that the multi-criteria decision analysis framework identifies anaerobic digestion as the most favorable option in terms of environmental performance and social acceptance (Makky et al., 2025). Incineration achieves the highest score for technical feasibility but ranks lowest in public perception due to concerns about emissions (Billah et al., 2024). Gasification is positioned as a balanced alternative, providing moderate energy output with lower emissions relative to incineration (Zaman, 2025). These literature review indicate that Dhaka should prioritize anaerobic digestion as the primary waste-to-energy technology, with gasification serving as a

complementary approach for non-biodegradable waste fractions. Policy recommendations include increased investment in waste segregation systems, implementation of public education initiatives, and integration of waste-to-energy solutions into Dhaka's comprehensive energy strategy. The current budget allocation for waste management is deemed insufficient. Overall, the analysis demonstrates that waste-to-energy represents not only a technical solution but also a strategic pathway toward sustainable urban development.

Table 5 : Municipal budget allocation by category (percentage)

Budget Allocation Category	Percentage of Total Municipal Budget	References
Waste management service	<1%	Jumman Sani (2025)
Road maintenance	10-15%	Jumman Sani (2025)
Water and sanitation	8-12%	Jumman Sani (2025)
Education and health services	15-20%	Jumman Sani (2025)
Administrative and other services	50-55%	Jumman Sani (2025)
Emergencies and contingencies	2-5%	Jumman Sani (2025)

Source: Jumman Sani (2025), Waste Management in Bangladesh: Current Practices, Challenges and Policy Directions.

4.6 Limitations

The findings of this study are subject to several limitations:

- The analysis relies exclusively on secondary data, which may contain inherent inaccuracies and lack the precision of primary field sampling.
- Energy potential calculations assume a steady state waste composition, although seasonal variations (e.g., monsoon moisture >80%) are addressed through scenario ranges.
- The lack of long-term operational data from large-scale WtE plants in Dhaka means performance indicators are based on international case studies and pilot projects.
- Economic feasibility is evaluated at a high level (via MCDA) rather than through detailed discounted cash flow analysis.

5. Conclusion and future study

This study investigates the potential for energy recovery from Dhaka's municipal solid waste and evaluates the most suitable technologies for this purpose. Results indicate that the waste stream, with an average calorific value of 6–8 MJ/kg, could generate 8,800 MWh per day if processed efficiently. Although plastics and paper constitute a smaller proportion of the waste, they contribute significantly to the overall energy potential, while organic materials are essential for biogas production. Under optimal conditions, including effective segregation and advanced technology, up to 15–20% of Dhaka's daily electricity demand could be met through waste-to-energy conversion (Hasan et al., 2024). However, current practices restrict recovery to 5–7%, highlighting a substantial gap between theoretical potential and actual performance.

The analysis highlights that no single waste-to-energy (WtE) technology can comprehensively resolve the waste management challenges faced by Dhaka. Incineration, while capable of delivering immediate energy recovery, raises significant concerns related to emissions, ash disposal, and long-term environmental sustainability. These drawbacks make it less suitable as a stand-alone solution in a city already struggling with air quality issues. Anaerobic digestion, on the other hand, aligns well with Dhaka's waste profile, given that organic matter constitutes the majority of municipal solid waste. With conversion efficiencies ranging between 30–40%, anaerobic digestion not only generates biogas but also produces digestate that can be used as fertilizer, thereby offering socio-economic benefits. However, its effectiveness depends on proper segregation of organic waste, which remains a major infrastructural challenge. Gasification emerges as a cleaner alternative for combustible fractions such as plastics and paper, producing syngas at efficiencies of 25–30%. This technology reduces reliance on landfills and minimizes harmful emissions compared to incineration. Taken together, these findings suggest that a hybrid strategy combining anaerobic digestion and gasification offers the most balanced approach for Dhaka's diverse waste streams.

.Under optimal conditions, including effective waste segregation and high technological efficiency, Dhaka could recover 15–20% of its daily electricity demand from municipal solid waste . Data from the different research papers underscores the significant potential of waste-to-energy systems when supported by robust infrastructure and effective governance.

Conversely, if waste remains unsorted and technology operates below optimal efficiency, electricity recovery may decline to 5–7% of daily demand. This scenario illustrates the risks associated with inadequate waste management and emphasizes the necessity of strong policy support. Enhancing public awareness, investing in segregation systems, and enforcing regulations are essential for realizing optimal outcomes.

Future research must prioritize pilot-scale implementation of hybrid WtE systems in Dhaka to assess their long-term operational sustainability. Pilot projects provide critical insights into technical feasibility, economic viability, and environmental performance under real-world conditions. They also allow researchers and policymakers to evaluate how seasonal fluctuations in waste composition affect energy recovery outcomes. For instance, organic waste volumes may rise during certain months due to agricultural cycles or festival seasons, influencing the efficiency of anaerobic digestion. Similarly, variations in plastic and paper waste can alter the performance of gasification units. Comprehensive modeling of these fluctuations is therefore essential to improve the accuracy of energy recovery projections and ensure reliable system design. Without such modeling, energy estimates may remain overly optimistic or fail to account for operational challenges. Pilot-scale studies also help identify bottlenecks in waste segregation, collection, and processing infrastructure. By addressing these issues early, policymakers can design interventions that enhance scalability and reduce risks associated with large-scale deployment.

Beyond technical and environmental considerations, socio-economic impacts must be integrated into future research on WtE systems in Dhaka. Job creation opportunities in waste collection, segregation, and plant operation can significantly improve community livelihoods. Cost-benefit analyses are necessary to determine whether hybrid systems provide financial advantages compared to traditional landfill disposal or single-technology approaches. Community acceptance is equally critical, as public perception often determines the success or failure of waste management projects. Biogas initiatives, for example, tend to receive greater acceptance when linked to agricultural benefits such as fertilizer production. In contrast, incineration projects frequently face opposition due to concerns about air pollution and health risks. Comparative analyses with other South Asian cities, such as Delhi or Colombo, may yield valuable lessons on effective policy frameworks and technology adaptation. These comparisons can highlight how governance structures, investment strategies, and community engagement influence outcomes. Ultimately, integrating socio-

economic dimensions ensures that WtE systems in Dhaka are not only technically feasible but also socially inclusive and economically sustainable.

Dhaka's municipal solid waste is not merely a disposal burden but a strategic energy resource. Unlocking this potential requires coordinated action across technology, governance, and society. If segregation rates improve and hybrid technologies are deployed, WtE could reduce dependence on landfills by 25% within the next decade and contribute meaningfully to Bangladesh's renewable energy targets. Future studies must bridge current research gaps and provide evidence-based pathways to transform waste management from a crisis into an opportunity for sustainable urban energy.

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