International Journal of Applied and Natural Sciences
ISSN: 3005-3471
DOI: 10.61424/ijans
Journal Homepage: www.bluemarkpublishers.com/index.php/IJANS

IJANS
BLUEMARK PUBLISHERS

| RESEARCH ARTICLE

Artificial Intelligence-Driven Optimization and Decision Support for Integrated Waste-to-Energy Systems in Climate-Vulnerable Megacities: A Case Study of Dhaka, Bangladesh

F. A. Samiul Islam

Independent Scientist and International Reviewer, Department of Civil Engineering, Uttara University, Dhaka, Bangladesh

Corresponding Author: F. A. Samiul Islam, **E-mail**: samir214100@yahoo.com

| ABSTRACT

The nexus of waste management and energy insecurity poses a critical challenge for climate-vulnerable megacities undergoing rapid urbanization. Dhaka, Bangladesh, A city marked by escalating solid waste generation, inadequate source segregation, overburdened landfills, and an overreliance on fossil fuels, epitomizes this crisis. This research investigates the transformative potential of Artificial Intelligence (AI) in optimizing integrated Waste-to-Energy (WtE) systems as a strategic response to urban sustainability deficits. Leveraging a multidisciplinary framework, this paper evaluates the contextual suitability of key WtE technologies- incineration, gasification, pyrolysis, and anaerobic digestion- based on Dhaka's high-moisture, organic-rich waste stream. This study presents a comprehensive architecture for AI-enhanced WtE operations encompassing predictive waste stream analytics, robotic sorting, dynamic process control, real-time emissions minimization, and intelligent decision support for urban planners. The synergistic integration of AI enables energy recovery from heterogeneous waste and enhances feedstock characterization, adaptive combustion tuning, and biogas optimization, thus significantly improving system efficiency and reducing lifecycle emissions. Case comparisons demonstrate that AI-based forecasting models achieve sub-1% error margins in waste volume prediction, outperforming conventional methods by over 85% in accuracy. Furthermore, the study underscores the broader implications of AI-driven WtE systems for climate resilience, circular economy integration, and energy security. Socioeconomic and governance barriers- such as the informal waste sector, policy fragmentation, and algorithmic bias- are critically examined, with targeted strategies proposed for ethical and equitable deployment. This work advocates a paradigm shift from linear disposal models to intelligent, regenerative urban metabolism. The proposed AI-WtE convergence offers a scalable, replicable blueprint for megacities globally to transition toward low-carbon, resource-efficient futures while reinforcing climate adaptation and public health resilience.

| KEYWORDS

Artificial Intelligence (AI), Bangladesh, Circular Economy, Climate-Vulnerable Megacities, Decision Support, Dhaka, Energy Security, Optimization, Sustainable Systems, Waste Management, Waste-to-Energy (WtE).

| ARTICLE INFORMATION

ACCEPTED: 28 March 2025 **PUBLISHED:** 03 June 2025 **DOI:** 10.61424/ijans.v3.i2.315

1. Introduction

In the context of accelerating climate change, the growing problems of waste management and energy insecurity constitute a crucial intersection for megacities sensitive to climate change worldwide. This dilemma is best illustrated in Dhaka, Bangladesh, which is struggling with increasing urbanization, trash production, and a high vulnerability to climatic impacts like floods and extreme weather. Due to low collection rates, a serious lack of source segregation, and overburdened landfills that pose serious risks to the environment and public health, the city's current waste management procedures are insufficient. At the same time, Dhaka's energy infrastructure is highly dependent on fossil fuels, creating a risky energy security position that is made worse by demand spikes brought on by climate change (Samiul, 2025). This research examines the transformative potential of Artificial Intelligence (AI) in optimizing sustainable Waste-to-Energy (WtE) systems as an integrated solution for Dhaka. It delves into the suitability of various WtE technologies- incineration, gasification, pyrolysis, and anaerobic digestion-considering Dhaka's unique waste composition and socio-economic context. The analysis highlights how AI can revolutionize WtE operations through predictive analytics, real-time process control, and enhanced resource recovery, thereby improving efficiency, reducing emissions, and fostering a circular economy. Notwithstanding the enormous potential, the research also discusses important obstacles to the implementation of AI, such as data privacy, viability from an economic standpoint, and the environmental impact of AI. The results highlight the need for a multifaceted strategy for successful WtE implementation in Dhaka. This entails major financial investment, focused capacity building, deliberate policy reforms, and strong public-private partnerships. Recommendations center on incorporating WtE into a larger climate adaptation and sustainable urban development strategy, pushing technology best suited to Dhaka's waste characteristics, and using AI to overcome current operational obstacles. Dhaka can improve energy resilience, alleviate its waste problem, and create a more sustainable and climate-resilient future for its most vulnerable citizens by adopting AI-driven WtE solutions (Islam, 2025).

Global urbanization has increased at an unprecedented rate in the twenty-first century, and megacities—urban regions with a population of ten million or more-are becoming important hubs of economic activity and human activity. There were just two of these cities in the world in 1950, but by now there are 34, and by 2030, there will be 43, and by the middle of the century, they will house 70% of the world's population (A Sustainable Future for Megacities? 2025). The current infrastructure and resources are under tremendous strain due to this rapid population growth, which is especially noticeable in emerging countries. There is an unbreakable relationship between this urban growth and rising resource consumption and trash production. According to A Sustainable Future for Megacities? (2025), cities today account for between 67% and 72% of global carbon dioxide (CO_2) emissions and a significant 70% of global energy consumption. Research shows a nearly proportional relationship between urban population size and CO_2 emissions, suggesting that as city populations grow, so do emissions (Islam, 2025). According to Cities and Climate Change (n.d.), population growth rates in quickly expanding megacities, particularly in Asia, can approach 4% annually, which can result in even higher emissions growth, sometimes reaching 10% annually. Municipal solid waste (MSW) is expected to reach 3.8 billion tons worldwide by 2050 if current trends continue, which would be a 56% increase over 2020 levels (A Sustainable Future for Megacities? 2025). Unwanted environmental, social, and economic effects are caused by suboptimal waste disposal methods, which are common in many urban areas (Social and Environmental Sustainability of Municipal Solid Waste in the Context of the UN Sustainable Development Goals – Bioenergy, n).

Concerning increases in atmospheric CO_2 and other greenhouse gas (GHG) concentrations have resulted from the world's growing reliance on fossil fuels, which are the main source of CO_2 emissions. According to the current trajectory, global warming is expected to reach a disastrous 3–4°C this century, which is significantly higher than the 1°C warming that is currently causing significant climate disturbances. Emissions are still rising in spite of international agreements like the 2015 Paris Agreement, which sought to keep rises in global temperatures far below 2°C (and ideally 1.5°C) over pre-industrial levels. The 1.5°C limit has already been exceeded, according to many climate scientists (Climate Change, Overshoot and the Demise of Large Cities, 2025). This interdependence identifies a crucial "Urbanization-Emissions Feedback Loop." Megacities' quick growth generates a self-reinforcing cycle in addition to economic benefits. Their expansion drives up energy consumption and waste production, which, when mismanaged or dependent on carbon-intensive sources, results in a proportionately higher, and frequently disproportionately higher, rise in greenhouse gas emissions. Urban areas, especially those with sensitive infrastructure, are disproportionately affected by climate hazards like heat waves and floods, which are made worse by these rising emissions. This dynamic emphasizes how urgently integrated, sustainable urban planning is needed to actively break this loop.

1.1 Research Objectives

This study aims to explore the intersection of Artificial Intelligence (AI) and Waste-to-Energy (WtE) systems as a sustainable solution for climate-vulnerable megacities, with a particular focus on Dhaka, Bangladesh. The primary objectives of the research are:

1) To evaluate the infrastructure, economic, and environmental obstacles that Dhaka has in managing solid waste and guaranteeing energy security in the face of rapidly increasing urbanization and climate change.
2) In light of the waste composition, moisture content, and calorific value of Dhaka, assess the sustainability and feasibility of various WtE processes (gasification, pyrolysis, anaerobic digestion, and incineration).
3) To look into how artificial intelligence (AI) may revolutionize garbage collecting, sorting, process control, emission management, and energy recovery systems along the whole value chain.
4) To analyze how AI can enhance strategic decision-making and operational efficiency through predictive analytics, real-time data integration, and adaptive system optimization in waste and energy management.
5) To identify existing policy, infrastructure, and governance gaps that hinder the successful integration of AI-driven WtE systems in developing megacities like Dhaka.
6) To propose an integrated, AI-enabled waste-to-energy framework for sustainable urban development, emphasizing climate adaptation, circular economy principles, and inclusive public-private partnerships.

2. Literature Review

1) **Current State of Waste Management in Dhaka:** Rapid urbanization and population expansion present major issues for Dhaka, the capital city of Bangladesh, in managing its municipal solid waste (MSW). The current landfills at Amin Bazar and Matuail are getting close to their capacity limits, even though more than 80% of the waste generated gets collected, according to a critical evaluation. These landfills' lack of gas capture technologies raises greenhouse gas emissions, endangering human health and the ecosystem (Khan, Haque, & Hossain, 2024).
2) **Waste-to-Energy Initiatives in Dhaka:** Bangladesh launched its first Waste-to-Energy (WtE) facility in North Dhaka to solve the growing waste management problems. This project entails building a plant with two 35 MW turbo-generator systems and four incinerator lines close to the Amin Bazar dump. As a major step toward sustainable waste management in the area, the goal is to remove municipal solid waste from landfills and produce renewable energy (Asian Infrastructure Investment Bank, 2024).
3) **Integration of AI in Waste Management:** The potential of artificial intelligence (AI) to revolutionize waste management procedures is becoming more widely acknowledged. AI-powered solutions can improve recycling procedures, optimize collection routes, and forecast waste generation patterns (Akther, Evans, & Millington, 2024). AI algorithms, for example, have been used to predict the composition of waste and recommend the best recycling practices, which lowers energy use and operating expenses (JR Recycling Solutions Ltd., 2024). Additionally, NANDO and other AI-powered tools use picture recognition to evaluate the quality of waste segregation, giving real-time data to enhance waste management procedures (International Telecommunication Union, 2024). By combining artificial intelligence (AI) with Internet of Things (IoT) devices, garbage containers can be monitored in real time, allowing for more effective collection and processing.
4) **Decision Support Systems for Waste-to-Energy Technologies:** Effective waste management depends on the use of suitable WtE technology. The purpose of Decision Support Systems (DSS) is to help evaluate different WtE choices according to technical, environmental, and financial factors. Policymakers and stakeholders can use these tools to help them make well-informed decisions that are relevant to the needs of cities like Dhaka (Asian Infrastructure Investment Bank, 2023; ScienceDirect, 2022).
5) **Potential of Hydrogen Energy from Waste:** The viability of generating hydrogen energy in Bangladesh from biomass and municipal solid waste has been investigated in recent studies. In addition to solving the problem of waste disposal, this strategy helps diversify the nation's energy sources, encourages a circular economy, and lessens dependency on fossil fuels (Hossain, Rahman, & Karim, 2021; Rahman & Ahmed, 2020).

2.1 The Operation of a Waste-To-Energy Power Plant

The process of turning common waste into useful energy is how a waste-to-energy (WtE) power plant operates. The first step in the process is burning municipal solid waste at extremely high temperatures. The waste emits heat during combustion, which a big boiler system uses to create steam. A turbine is powered by this steam, much like in a conventional power plant, and the turbine produces energy. The generated energy can be added to the grid to power residences and commercial buildings. The fact that WtE converts garbage that would otherwise wind up in landfills makes it a renewable energy source (Ketul, 2024).

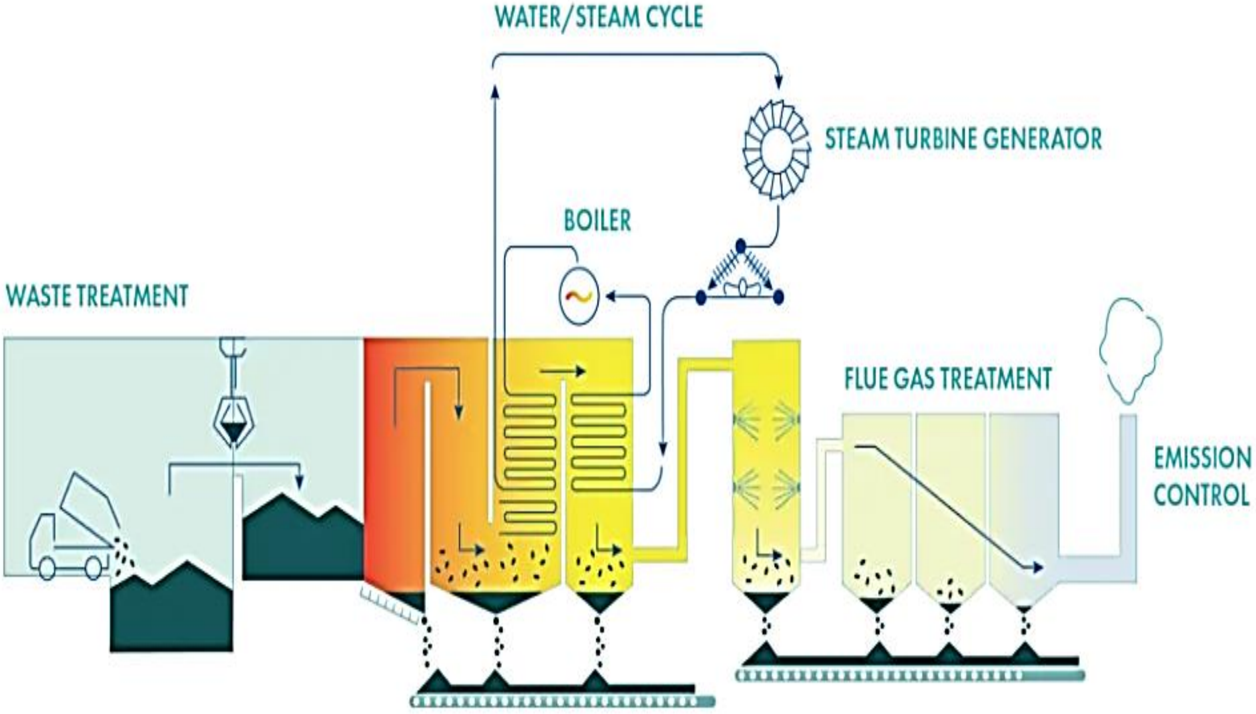


Figure 01: Process Flow Diagram of a Waste-to-Energy (WtE) Power Plant (Source: Ketul, 2024).

Advanced filters and scrubbers are used to eliminate dangerous pollutants from the flue gases emitted during combustion, ensuring that the process is safe for the environment. While hazardous fly ash is carefully handled to prevent environmental contamination, the process's leftover ash can occasionally be used again in the building (Daga, 2024).

- **Advantages and Disadvantages of Waste-to-Energy Plants:**

Waste-to-Energy (WtE) facilities provide a comprehensive approach to energy production and waste management, with both noteworthy advantages and disadvantages. Mission Sustainability claims that although these facilities are essential to contemporary waste systems, they also present several difficulties. On the advantageous side, WtE plants notably reduce the volume of waste destined for landfills, converting garbage into ash and thereby cutting landfill waste by up to 90%. This process directly contributes to reducing methane emissions from landfills, as less trash is left to decompose and produce this potent greenhouse gas. Consequently, the demand for new land to accommodate waste is diminished, leading to reduced land requirements for disposal sites. Furthermore, WtE systems are highlighted for offering renewable energy benefits, contributing to a greener energy portfolio.

However, the operation of WtE plants is not without its concerns. A primary disadvantage stems from toxic waste emissions**;** the incineration process can transform inert hazardous waste into bioavailable hazardous and toxic emissions. The article specifically cites a study mentioning the emission of substances such as lead, mercury, cadmium, nitrous oxide, sulfur dioxide, hydrogen chloride, sulfuric acid, fluorides, and particulate matter. Another drawback is their lower productivity compared to traditional energy sources, where one ton of waste generates electricity equivalent to only one-third of what coal can produce. The need for waste sorting, which can be a laborious procedure, and the general problems of high capital costs, continuous emission concerns, and relatively poorer energy efficiency when compared to other truly renewable energy sources are practical obstacles. Overall, even though WtE plants have a lot to offer in terms of reducing waste volume, mitigating methane emissions, and conserving land, these advantages need to be carefully weighed against issues with efficiency, emissions, and a large initial outlay of funds (Ketul, 2024).

3. Methodology

This study adopts a comprehensive, qualitative, and analytical research approach to explore the transformative potential of Artificial Intelligence (AI) in optimizing integrated Waste-to-Energy (WtE) systems within the context of climate-vulnerable megacities, with a specific focus on Dhaka, Bangladesh. The methodology encompasses several key stages:

1. Research Design and Approach:

The research is conceptual and analytical, primarily relying on a robust synthesis of existing literature, scientific reports, and policy documents. It is structured as a case study focusing on Dhaka to provide a contextualized understanding of the challenges and proposed solutions. The aim is to develop a conceptual framework for AI-driven waste-to-energy integration rather than conducting empirical data collection or modeling.

2. Scope of Study:

The study's geographic focus is restricted to Dhaka, Bangladesh, a megacity that is a prime example of a climate-vulnerable city with serious waste management and energy security issues. The thematic scope consists of:

- An examination of the flaws of Dhaka's current garbage management procedures.
- Evaluation of different WtE technologies (gasification, pyrolysis, anaerobic digestion, and incineration) for their applicability to the waste composition of Dhaka.
- Investigation of the possible and existing uses of artificial intelligence to improve the optimization, decision support, and efficiency of WtE systems.
- Examination of the relationship between energy security, waste management, and climate change resistance in urban settings.

3. Data Collection and Information Synthesis:

Information for this study was meticulously gathered through a comprehensive literature review. This involved:

- **Academic Databases:** Searching for peer-reviewed articles, conference papers, and scholarly publications on AI in waste management, WtE technologies, urban waste challenges, climate change impacts on cities, and sustainable development in relevant databases (e.g., Scopus, Web of Science, Google Scholar, ResearchGate).
- **Government Policy Documents and Reports:** Examining environmental policies, urban development plans, and national and local government reports about waste management, energy, and climate change in Bangladesh.
- **Reputable Online Sources:** Examining studies and reports on urban sustainability, renewable energy, and artificial intelligence developments from global organizations, academic institutions, and respectable news sources.

After that, the collected data was methodically examined and combined to pinpoint important patterns, difficulties, innovations in technology, and best practices that were pertinent to the study's goals.

4. Framework Development and Analysis:

Based on the synthesized information, the study developed an integrated conceptual framework for AI-driven waste-to-energy systems for Dhaka. This involved:

- **Problem Identification:** Clearly stating the unique issues with energy insecurity and waste management in Dhaka.
- **Technology Suitability Assessment:** Assessing the suitability of various WtE technologies in light of the socioeconomic environment and the distinctive waste characteristics of Dhaka (high organic content, lack of segregation).
- **AI Application Mapping:** Determining particular domains, such as waste characterization, feedstock management predictive analytics, real-time process control, maintenance optimization, and resource recovery enhancement, where AI can be used to optimize WtE processes.
- **Identification of Synergy:** Illustrating how combining AI and WtE technology can result in increased energy security, resource recovery, efficiency, and a smaller environmental impact.
- **Policy and Implementation Considerations:** The successful adoption and expansion of such integrated systems in megacities that are sensitive to climate change requires the formulation of strategic recommendations and policy considerations.

5. Socio-Economic and Environmental Impact Assessment:

A qualitative evaluation of the possible socioeconomic and environmental effects of deploying AI-driven WtE systems in Dhaka was also part of the research. This involved assessing:

- **Social Implications**: Social Implications: addressing any algorithmic biases, making sure that solutions are human-centered, and taking into account the effects on the informal waste sectors.
- **Energy Security Benefits:** Energy security advantages include localized power generation and energy source diversification.
- **Economic Benefits:** Economic benefits include possibilities for private sector investment, resource recovery value, and the development of jobs, particularly skilled labor.
- **Environmental Benefits:** Benefits to the environment include a decrease in pollutants, greenhouse gas emissions, and landfill load.

The study intends to offer a comprehensive knowledge of how AI might act as a catalyst for sustainable energy and waste management solutions, enhancing urban resilience in megacities that are vulnerable to climate change, by combining these analytical elements.

3.1 Identifying Megacities at Risk from Climate Change and Their Particular Difficulties

Megacities, especially those in developing countries, face a wide range of intricate environmental issues. (A Sustainable Future for Megacities? 2025) lists these as extreme air and water pollution, growing resource shortages, and the urban heat island effect, which makes metropolitan temperatures noticeably warmer than those of nearby rural areas. Climate change significantly exacerbates these urban problems. Rising sea levels, more frequent and severe extreme weather events (such as floods, droughts, and storms), and the spread of tropical diseases are just a few of the effects that have a significant and expensive impact on public health, infrastructure, housing, human livelihoods, and essential urban services (Cities and Climate Change, n.d.; Moon, 2024; Campbell-Lendrum & Corvalán, 2007; Islam, 2025).

High population density, poor urban design, and insufficient infrastructure worsen pollution and resource strain in many emerging nations. Urban slums, for example, experience increased pollution and resource strain due to high population density, inadequate infrastructure, and a lack of waste management planning. Because they frequently lack the adaptation capacity seen in certain industrialized countries, vulnerable populations in tropical developing cities are especially vulnerable to the effects of climate change. Due to the urban heat island effect, which causes cities to be 5-11°C warmer than their rural surroundings, they are more vulnerable to heat waves. Additionally, because of their coastal locations, the loss of natural protection (such as deforestation), the poor quality of homes constructed on exposed slopes, and the massive concrete surface without proper drainage, they are more vulnerable to floods and storms (Campbell-Lendrum & Corvalán, 2007; Islam, 2025).

Climate-vulnerable megacities' current infrastructure deficiencies actively increase their populations' susceptibility to the effects of climate change rather than just failing to mitigate them. For instance, the pre-existing bad infrastructure, such as vast impervious surfaces and inadequate drainage systems, directly leads to flash floods and water stagnation when extreme weather events, such as heavy rainfall and floods, accelerate due to climate change. Unmanaged garbage and these infrastructure breakdowns subsequently result in serious health risks, such as waterborne illnesses and ideal mosquito breeding grounds, which cause dengue and other disease outbreaks. This implies that climate events become exacerbated environmental and public health problems when they combine with pre-existing infrastructure flaws. As a result, rather than being a secondary priority, climate adaptation plans in these situations must essentially emphasize the creation of a strong and durable infrastructure.

3.2 Waste-To-Energy's (Wte) Potential as an Integrated Approach

One essential method of energy recovery is waste-to-energy (WtE), sometimes referred to as energy-from-waste, which converts non-recyclable garbage into useful energy sources like heat or electricity. Using waste that would otherwise end up in landfills, this procedure establishes WtE as a renewable energy source (Daga, 2024). WtE technologies provide several benefits, including a considerable reduction in waste volume (up to 90%), mitigation of landfill methane emissions (a powerful greenhouse gas), and a reduction in the amount of land needed for waste disposal (Daga, 2024).

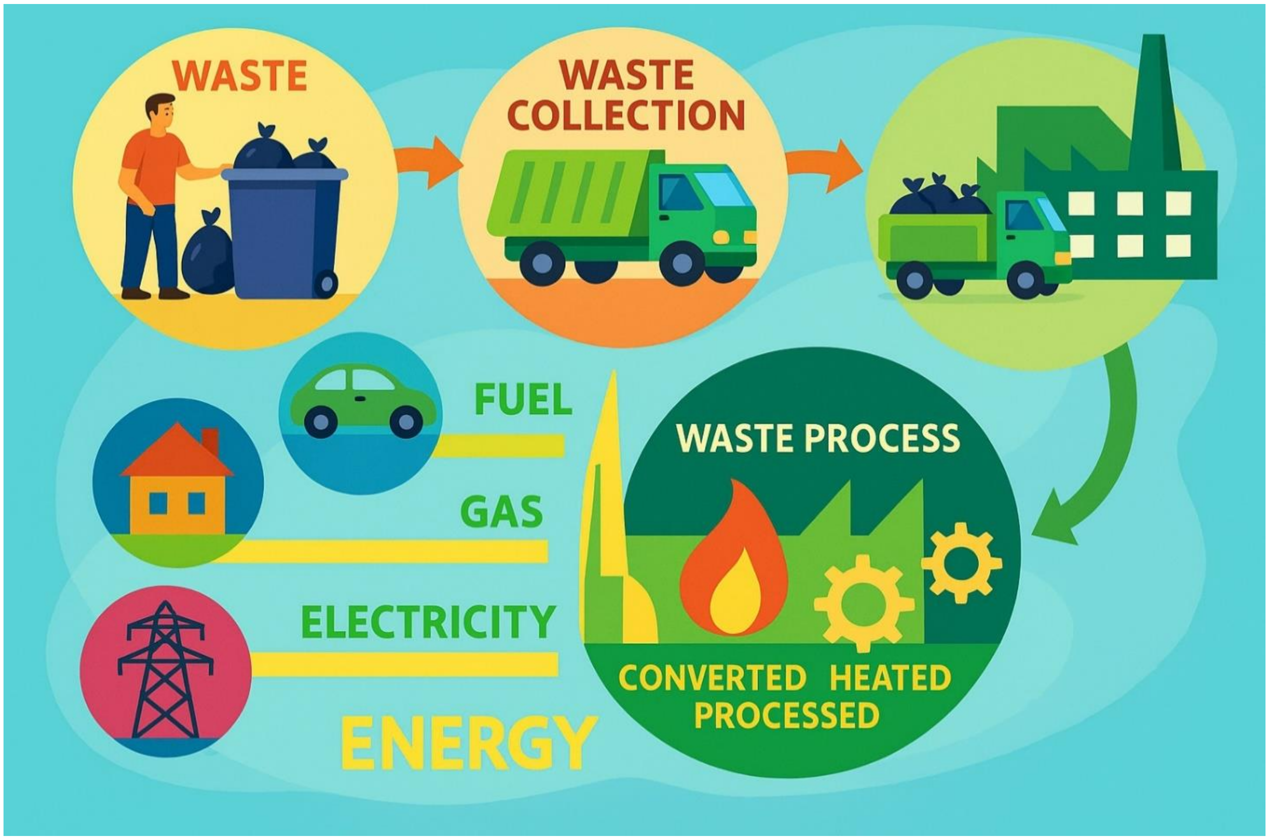


Figure 02: Waste-to-energy (Source: Daga, 2024).

Beyond waste management, WtE directly reduces air pollution and mitigates climate change by keeping garbage out of landfills and utilizing its energy potential (AlexTabibi, 2024). Furthermore, by requiring competent staff and producing tax income, the development and operation of WtE facilities have the potential to boost local economic growth and create jobs (Job Creation and Economic Growth, n.d.; AlexTabibi, 2024).

When carried out responsibly, WtE systems serve as a potent "multi-SDG accelerator," accelerating the achievement of multiple important SDGs at once. WtE supports SDG 11 (Sustainable Cities and Communities) by lowering waste volume, reducing methane emissions, and reducing landfill space. SDG 7 (Affordable and Clean Energy) is directly supported by the production of heat and electricity from trash. Additionally, WtE helps achieve SDG 13's (Climate Action) primary goal of lowering greenhouse gas emissions by diverting trash from landfills and recovering energy. Using WtE facilities to create jobs and boost local economic growth is also in line with SDG 8 (Decent Work and Economic Growth). This potential is dependent on strict environmental controls and cautious technological selection, though, to make sure that the quest for energy recovery doesn't unintentionally result in additional environmental or health costs. Waste-To-Energy Technology Explained & Examples, Perch Energy, n.d.; Murphy & Gusciute, 2024; Daga, 2024). For example, if not managed properly, some WtE technologies, like incineration, can produce harmful emissions, requiring a holistic sustainability assessment that takes environmental, economic, and social factors into account.

3.3 Presenting Artificial Intelligence (AI) As A Revolutionary Facilitator for Waste-To-Energy Optimization

Artificial Intelligence (AI) has the potential to transform energy recovery and waste management by streamlining procedures, increasing productivity, cutting expenses, and boosting operations for a variety of waste kinds (Amazon.com, n.d.). Dynamic solutions for forecasting garbage creation trends, streamlining collection routes, and greatly improving sorting and recycling procedures are made possible by AI and Machine Learning (AI&ML) technologies, which can analyze large datasets in real-time (Rautela et al., 2025). Compared to conventional approaches that depend on manual data collection and static models, this represents a significant shift. Importantly, integrating AI into WtE processes improves operational efficiency and helps reduce greenhouse gas emissions by increasing energy recovery and decreasing pollutant output (Vivatechnology, n.d.). The potential of AI to turn trash from a liability into a lucrative resource is highlighted by this twofold contribution (Rautela et al., 2025).

Artificial intelligence (AI) has the potential to revolutionize management in complicated urban contexts by bridging the crucial "data-to-action" gap. Urban energy and waste management systems are intrinsically complicated, with many moving parts, dynamic fluxes, and enormous datasets. Real-time data analysis and adaptive decision-making are frequently difficult for traditional management techniques, which results in inefficiencies and less-than-ideal results. But AI and machine learning are better at processing large volumes of data, finding intricate patterns, forecasting outcomes, and real-time dynamic system optimization (Rautela et al., 2025). The efficiency, sustainability, and resilience of WtE systems are improved in a way that was previously impossible with traditional methods thanks to artificial intelligence (AI), which transforms raw data into actionable insights and permits automated, adaptive optimizations. In dynamic, climate-vulnerable megacities where quick reactions are crucial, this is especially important (Vivatechnology, n.d.; Rojek et al., 2025).

3.4 The Environmental and Socioeconomic Situation of Dhaka: A Megacity on the Frontline of Climate Change

Bangladesh is one of the most climate-vulnerable countries in the world (Moon, 2024). Significant direct and indirect effects of climate change are being disproportionately felt by Dhaka, the capital, and a rapidly growing megacity (Mortoja & Yigitcanlar, 2020). Rising sea levels, rising temperatures, salinity intrusion, increased storm surges, increased frequency and intensity of tropical cyclones, and general regional climate unpredictability—which means more devastating floods, droughts, and severe storms—are the main climate threats facing Bangladesh (Moon, 2024). With monsoon rainfall (May to September) providing over 78% of its significant 2148 mm average annual rainfall, Dhaka in particular endures regular flooding each year (Mortoja & Yigitcanlar, 2020). In addition to worsening flooding and providing ideal breeding grounds for disease-carrying insects like mosquitoes, this high rainfall, along with a large number of open disposal sites and shoddy open drainage infrastructure, can result in dengue outbreaks (Heng, 2025). In Bangladesh, internal migration is also significantly influenced by climate change.

Dhaka is home to an astounding 68% of the nation's estimated two million climate migrants. The lowest sections of the population are mostly represented by these migrants, who frequently settle in the city's most vulnerable peripheries, which are particularly vulnerable to the effects of climate change.

There are serious and pervasive health consequences, such as an increase in vector-borne illnesses (e.g., dengue, malaria), respiratory ailments, malnourishment, and waterborne infections (e.g., cholera, newborn diarrhea due to limited clean drinking water and contaminated sources). These climate-related stressors have a significant impact on human and mental health (Moon, 2024; Abubakar et al., 2022). The most vulnerable urban residents in Dhaka are bearing a "triple burden" as a result of climate change. First, because their low-lying, poorly protected communities are disproportionately affected by frequent floods and other extreme weather events, these populations are directly exposed to increased climate threats. Second, forced internal migration brought on by climate change causes a large influx of poor people into Dhaka. Due to financial limitations and a lack of other options, these climate migrants are frequently forced to relocate to high-density, informal, flood-prone areas, further taxing already underdeveloped waste management and infrastructure systems. Third, these informal settlements' severe infrastructure and waste management deficits, precarious living circumstances, and direct climate dangers all contribute to increased pollution, resource strain, and the prevalence of vector-borne and waterborne illnesses. This intricate interaction calls for integrated urban design that goes beyond straightforward mitigation to include thorough climate adaptation, fair resource allocation, and strong public health initiatives that address these vulnerabilities in particular.

3.5 Artificial Intelligence as a Driver for Better Decision Support in Waste-To-Energy Systems

AI serves as a powerful analytical engine that offers actionable insights that enable human decision-makers and urban planners to make more informed and timely decisions on energy and waste management systems. Its role goes much beyond simple process automation. In dynamic, climate-vulnerable megacities like Dhaka, where conventional, static models frequently fail to address quickly changing conditions, this skill is especially important (Rautela et al., 2025). Here's how AI provides robust decision support:

i. **Predictive Analytics for Strategic Planning:** AI and machine learning (ML) algorithms are able to anticipate trash generation patterns with amazing accuracy, sometimes reaching up to 85% precision, by analyzing large historical datasets, including socio-economic aspects (Rautela et al., 2025). Future trash volumes and compositions may be predicted by city authorities thanks to this predictive capability, which is crucial for strategic planning. To avoid overloading the system, for example, proactive resource allocation for collection, treatment, and the construction of required infrastructure is made possible by understanding expected waste growth (Rana et al., 2025). For cities struggling with fast urbanization, this is a crucial change as it shifts planning from reactive to proactive.

ii. **Optimizing Resource Allocation and Operational Efficiency:** In addition to predicting, AI creates optimization models that greatly improve operational effectiveness and resource allocation. According to studies, AI can boost operational efficiency for waste management resource allocation by 15% (Rautela et al., 2025). This implies that AI can help with judgments about the optimal use of available staff, sorting facility management, and collection vehicle deployment locations, which will reduce costs and enhance service quality. AI has a direct impact on sustainability and profitability for WtE plants by optimizing feedstock supply and process parameters in real-time, guaranteeing maximum energy extraction, and minimizing waste (Vivatechnology, n.d.).

iii. **Real-Time Data Integration for Adaptive Management:** AI solutions make it easier to integrate data in real time from a variety of sensors and Internet of Things devices across the energy and waste management infrastructure (Rojek et al., 2025). An "unprecedented insight" into operations is provided by this constant flow of data, enabling quick modifications and better decision-making (Routeware & Team, 2025). For instance, AI may use sophisticated spectroscopy techniques to assess real-time data on waste composition (e.g., moisture content, calorific value) in minutes as opposed to hours, delivering crucial information (AG Solution - Story - Waste-to-Energy Optimization With AI, n.d.). To ensure optimal energy output and lower emissions, WtE facilities must be able to dynamically adapt their processes (such as combustion settings or biogas digester conditions) to changes in incoming garbage (AI to Increase garbage-to-energy Production, 2022).

iv. **Informing Urban Planning and Targeted Interventions:** The analytical capabilities of AI extend to more general urban planning. AI can identify regions with high waste production or pollution hotspots by examining environmental data and trash-generating patterns. City officials can use this data-driven method to make well-informed decisions on the implementation of particular environmental regulations, the launch of targeted public awareness campaigns, and the strategic placement of new recycling facilities (Vivatechnology, n.d.-e). AI may also model the effects of various waste management scenarios on air quality in climate-vulnerable cities, boosting public health actions by identifying pollution sources and guiding evidence-based policies (Heng, 2025; Rautela et al., 2025).

Energy and waste management are closely related sectors and artificial intelligence (AI) simply transforms raw data into usable information, providing decision-makers with the precision and insight they need to make informed decisions.

3.6 Comparative Analysis of Waste to Energy Technology Configurations in Dhaka

The waste characteristics of Dhaka, which include high levels of moisture (62.76%–80%) and organic content (54.92%–72%), necessitate a targeted and systematic assessment of Waste-to-Energy (WtE) solutions. Based on technological compatibility, environmental impact, energy efficiency, and economic viability in the context of Dhaka, the following compares four key WtE technologies.

Technology	Suitability for Dhaka	Key Advantages	Key Limitations
Incineration	Low-Moderate	Drastically reduces waste volume (up to 90%), capable of high-throughput energy production.	Low calorific value of Dhaka's MSW makes combustion inefficient without supplemental fuel, risk of toxic emissions, and high capital costs.
Anaerobic Digestion (AD)	High	Ideal for Dhaka's organic and moist waste; produces biogas and nutrient-rich digestate; low emissions.	Methane capture must be effective; needs robust source segregation; and low energy density.
Gasification	Moderate	Can process semi-dry waste into syngas; flexible energy applications; lower emissions than incineration.	Requires drying and pre-treatment; high technical complexity; capital-intensive.
Pyrolysis	Moderate-Low	Produces bio-oil, gas, and biochar; carbon-negative potential through biochar application.	Not ideal for moist, heterogeneous MSW; net energy balance may be negative due to high drying energy demand.

Table 01: Comparative Suitability of Waste-to-Energy (WtE) Technologies for Dhaka Based on Waste Characteristics and Operational Context (Sources: Islam (2016); Daga (2024); Murphy & Gusciute (2024); Khan & Kabir (2019); Rashid (2019); Shovon et al. (2024); and IEA Bioenergy Task 36 (2025)).

The best technique for Dhaka is Anaerobic Digestion (AD), especially when it comes to handling separated organic waste. Although it is feasible in some situations, incineration is energy-inefficient without pretreatment due to its low Lower Heating Value (LHV) and high moisture content. Although they need more financial investment and technological capability than Dhaka presently has, gasification and pyrolysis show potential.

3.7 Deeping AI-Technical Integration in Waste-To-Energy Systems

The integration of Artificial Intelligence (AI) into Waste-to-Energy (WtE) systems must move beyond general claims of "efficiency" to a detailed technical understanding of how AI algorithms interact with specific operational stages. This involves mapping data flows, selecting appropriate models, and optimizing decisions based on real-time analytics.

a) AI Workflow in the Waste-to-Energy Value Chain:

A structured AI integration framework in WtE systems involves four layers: data acquisition, model development, system optimization, and decision support. Figure 03 illustrates an AI-driven waste-to-energy workflow Architecture.

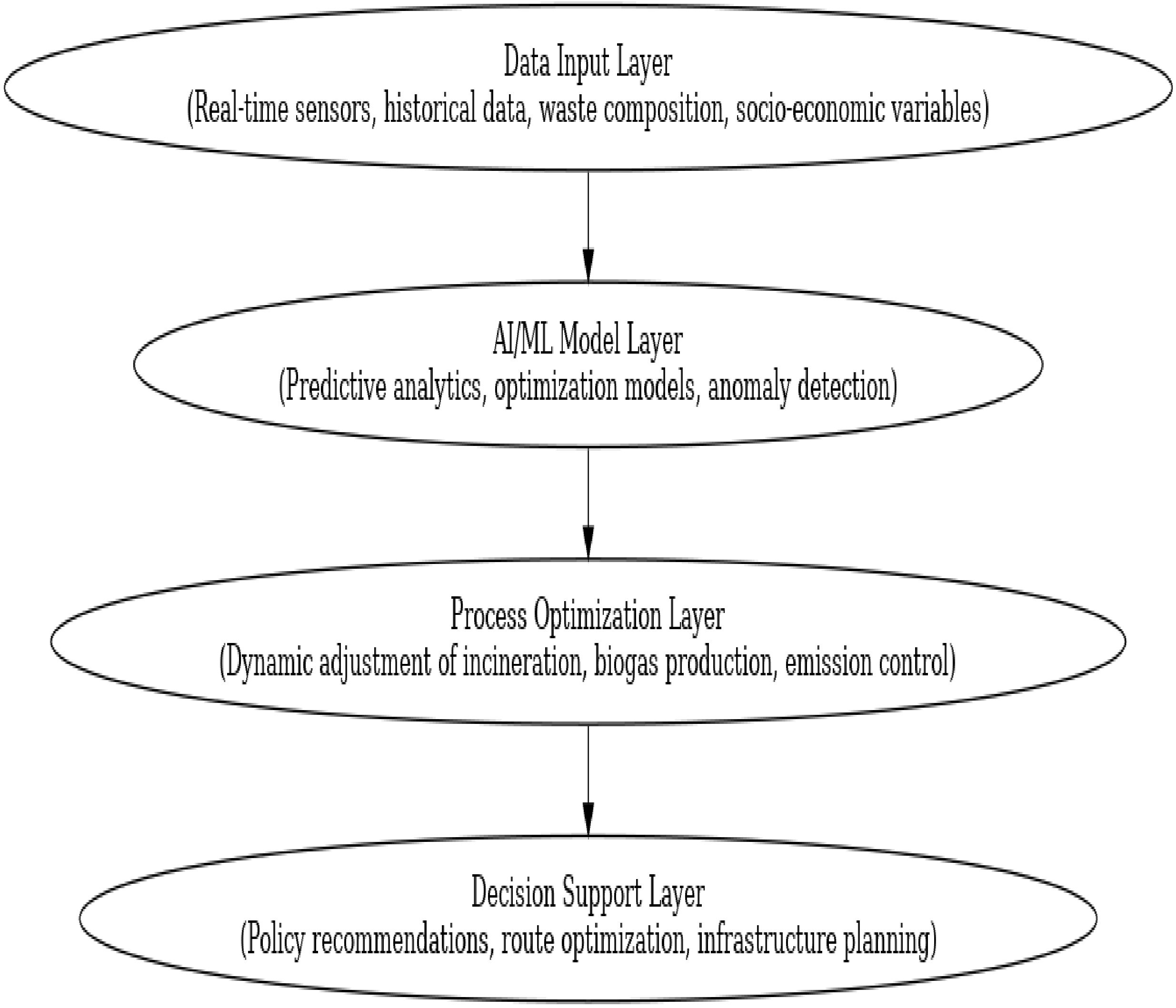


Figure 03: AI-Driven Waste-to-Energy Workflow Architecture (Sources: Rautela et al. (2025), Rana et al. (2025), and Rowe (2025)).

AI/ML Algorithm	Type	Suitable Applications in Waste-to-Energy	Strengths	Limitations
Random Forest	Supervised (Ensemble)	Waste generation forecasting; feedstock classification	High accuracy; handles nonlinear relationships well	Slower in real-time applications; interpretability issues
Support Vector Machine (SVM)	Supervised	Sorting recyclable materials, classifying waste streams	Effective for small/medium datasets; high precision	Poor scalability for large datasets
Convolutional Neural Network (CNN)	Deep Learning	Vision-based robotic sorting: object detection in waste	Excellent for image recognition and real-time automation	Requires large training data and computational power
XGBoost	Supervised (Ensemble)	Emission prediction: Optimizing energy output	Fast, high-performance; handles missing data well	Complex to tune; less interpretable
K-Means Clustering	Unsupervised	Grouping waste zones based on generation behavior	Simple, useful for segmentation	Limited to numeric data; assumes spherical clusters
Reinforcement Learning (RL)	Semi-supervised	Real-time process control in biogas reactors: combustion tuning	Adaptive; learns from dynamic environments	Requires extensive interaction data; slower convergence

Table 02: Artificial Intelligence/Machine Learning Algorithms and Their Suitability for Waste-to-Energy Applications.

b) Case Mapping for Use:

- CNN is ideal for AI-driven robotic sorting systems, where accurate material identification on conveyor belts is essential.
- Random Forest and XGBoost excel in predicting waste volumes, energy output, or emissions based on large datasets.
- SVM is suitable for high-precision classification tasks.
- Reinforcement Learning is promising for the continuous optimization of WtE plant parameters.

Selecting the right AI model for the right stage of the WtE lifecycle is essential. While general AI adoption improves automation, targeted integration of appropriate algorithms enhances system intelligence, responsiveness, and sustainability. Future WtE frameworks should be built around adaptive, explainable, and efficient AI architectures tailored to the waste and energy characteristics of specific megacities like Dhaka.

3.8 Evaluating AI Intervention Outcomes in Waste Generation Forecasting

Efficient planning of collection systems, resource allocation, and WtE facility sizing all depend on accurate forecasting of municipal solid waste (MSW) generation. Static historical averages and manual predictions are the foundation of traditional approaches in Dhaka, which frequently result in overestimations or underestimations. AI-based models dynamically analyze socioeconomic, seasonal, and regional variables, providing a significant improvement.

Case Comparison: Traditional vs. AI-Powered Forecasting.

Forecasting Method	Predicted Waste Generation (2024)	Actual Waste Generation (2024)	Error Margin	Comments
Traditional Linear Projection	6,100 tons/day.	6,500 tons/day.	~6.2% under-prediction.	Failed to account for population influx, informal settlements.
AI-Powered Model (ML-based, e.g., Random Forest)	6,470 tons/day.	6,500 tons/day.	~0.46% under-prediction.	Incorporated climate-driven migration, rainfall impact, and festival season spikes.

Table 03: Comparison of Traditional vs. AI-Based Municipal Waste Forecasting Accuracy in Dhaka (2024) (Sources: Rautela et al. (2025); Rana et al. (2025); and Routeware & Team (2025)).

Outcome Analysis:

- **Accuracy**: AI-driven models reduced prediction error from ~6% to <1%.
- **Adaptability**: Able to account for nonlinear factors such as flash flood-induced displacement, policy changes (e.g., new market zone), and sudden public holidays.
- **Actionability**: Real-time predictive analytics enabled optimized bin deployment and dynamic route scheduling, improving collection coverage by up to 15% (Rautela et al., 2025).

AI-based forecasting significantly outperforms traditional methods in both accuracy and utility. For Dhaka, where waste generation patterns are volatile due to urban migration, climate variability, and economic shifts, predictive analytics is critical to ensuring the long-term success of WtE systems.

3.9 Sustainable Urban Development Requires Integrated Waste-To-Energy Systems

It places a strong emphasis on integrating different approaches, tools, and legislative frameworks to produce a coherent and long-lasting solution, which is especially important for megacities like Dhaka that are dealing with complex environmental and socioeconomic issues. Here's why an integrated approach is imperative:

i. **Addressing Diverse Waste Characteristics:** The municipal solid waste (MSW) of Dhaka has a very low Lower Heating Value (LHV) due to its high moisture content (62.76% to 80%) and a high proportion of organic matter (54.92% to 72%) (Murphy et al., 2025). This diverse waste stream might not be appropriate for a single WtE technology (Murphy & Gusciute, 2024). Technologies would be strategically combined in an integrated system:
    - **Anaerobic Digestion (AD):** The high organic and moisture content makes it ideal for generating digestate for fertilizer and biogas for energy (Daga, 2024).
    - **Thermal Technologies (Incineration, Gasification, Pyrolysis):** Able to manage the leftover mixed garbage, particularly if it has been pre-sorted to boost its calorific content. Gasification and pyrolysis provide a variety of energy applications and can generate biochar for carbon sequestration, but incineration drastically reduces volume (IEA Bioenergy Task 36, 2025). By applying the best technology to each waste fraction, an integrated approach maximizes energy recovery and reduces environmental effects (Daga, 2024).

ii. **Synergy with Broader Waste Management Strategies (3R):** Reduce, Reuse, and Recycle (3R) are given priority in a comprehensive waste management hierarchy, and an integrated WtE system is not an "end-of-pipe" solution (IEA Bioenergy Task 36, 2025). Effective source segregation is essential because it raises recycling and composting rates and enhances the quality of feedstock for WtE processes (United Nations in Bangladesh, 2024). To facilitate source segregation and guarantee that only non-recyclable and non-compostable waste is sent to WtE facilities, an integrated system would fund infrastructure and public awareness initiatives (The Government of Bangladesh Announces Its Solid Waste Management Rules 2021, Department of Economic and Social Affairs, 2021; Samiul, 2023).

iii. **Holistic Sustainability Assessment:** A multi-criteria analysis that takes sustainability's social, economic, and environmental aspects into account is necessary for an integrated approach. This avoids less-than-ideal choices that could prioritize one factor (like energy production) while disregarding others (like air pollution or social justice) (Murphy & Gusciute, 2024). For example, an integrated approach would take into account the possibility of job displacement in the informal waste industry and guarantee equitable benefits for communities, even while WtE facilities generate employment (Abubakar et al., 2022).

iv. **Addressing Policy and Infrastructure Gaps:** Inadequate infrastructure, a lack of waste segregation, and poorly managed landfills, along with a "policy-practice disconnect" (Rautela et al., 2025), provide serious problems for Dhaka. For an integrated system to be implemented successfully, strong policy frameworks, funding, and interagency cooperation are necessary. Building overall urban resilience also requires incorporating waste management into larger urban planning and climate adaptation initiatives (Islam, 2021).

By embracing an integrated approach, Dhaka can move towards a more resilient, resource-efficient, and environmentally sound future, transforming its waste crisis into a sustainable energy and development opportunity.

3.10 Dhaka's Present Waste Production and Composition: Amounts, Organic Predominance, and Moisture Content

With Dhaka alone handling close to 6,500 tons per day, Bangladesh produces about 25,000 tons of waste daily (United Nations Bangladesh, 2024, May 24). Forecasts suggest that by 2032, this daily amount would rise to 8,500 tons (Zuhra, 2025), and by 2041, Bangladesh's overall trash generation rate is anticipated to reach an astounding 142,322 tons per day (United Nations Bangladesh, 2024, May 24). Particularly, the Amin Bazar Landfill disposes of about 2774 tons of the 4220 tons of trash produced daily by the Dhaka North City Corporation (DNCC) (Choudhury, 2025; Rashid, 2019). In Dhaka, the majority of the garbage is organic. Between 54.92% and 72% of the total garbage produced, especially at the Amin Bazar Landfill, is made up of food and organic waste. Paper waste makes up 12.60% and plastic garbage 14.70% (Rashid, 2019). It is important to note that this high organic content leads to a very high moisture content, usually between 62.76% and 80% by weight (Rashid, 2019). The municipal solid waste's (MSW) low Lower Heating Value (LHV) is directly caused by its high moisture content. The LHV of MSW that reaches Amin Bazar Landfill, for example, is roughly 2.753 MJ/kg. When the higher-heat value recyclable portion is taken into account, the LHV of 5.64 to 6.94 MJ/kg is much higher than this (Rashid, 2019; Hai & Ali, 2005). A significant contributing cause to this low LHV is the widespread informal resource recovery industry. Before the waste reaches formal disposal or waste-to-energy (WtE) facilities, informal recyclers remove high-heat value waste materials such as plastics, paper, textiles, and metals. The energy composition of the remaining waste stream intended for WtE conversion is further degraded by this process, which authorities sometimes ignore in their planning (Rashid, 2019).

Even while it generates income and helps recover some resources, Dhaka's informal garbage collecting and recycling industry unintentionally poses a paradoxical problem for official WtE programs (Samiul, 2023). Low Lower Heating Value (LHV) is a natural consequence of the high organic and moisture content of Dhaka's trash. Before the waste stream reaches official WtE facilities, high-heat value components, including plastics, paper, textiles, and metals, are removed by informal waste pickers in search of precious resources. The LHV of the residual trash is further decreased by this informal pre-sorting, rendering thermal WtE operations like incineration considerably less effective or even impossible without a major additional fuel input. To manage feedstock quality, this suggests that effective WtE strategies in Dhaka must either strategically prioritize WtE technologies that are naturally suited to high-organic, high-moisture waste streams that are less affected by informal extraction or formally integrate or work with the informal sector.

3.11 Current Issues with Solid Waste Management: Landfill Strain, Segregation Deficiencies, and Collection Gaps

Bangladesh's solid waste management (SWM) system has serious flaws, notwithstanding the startling rise in garbage production. Around 55% of urban solid garbage in the country is not collected, which exacerbates pollution, poses health hazards to the population and fuels climate change (United Nations Bangladesh, 2024, May 24). Even though Dhaka has a comparatively higher collection efficiency of 77-80%, just 17-20% of the waste produced every day is picked up. These problems stem from a widespread lack of waste segregation at the source, inadequate infrastructure, and poorly managed landfills, all of which contribute to significant environmental harm (S. Islam & ASEF Education Department, 2021). The current SWM system is insufficient to keep up with the estimated doubling of waste volume every 15 years (Islam, 2016).

One significant shortcoming is waste segregation at the source. The provision of various bins as part of a trial 3R (Reduce, Reuse, Recycle) strategy was mainly unsuccessful because of a lack of public knowledge and incentive among waste collectors and citizens (Samiul, 2023). As a result, garbage is frequently intermingled at disposal sites and during pickup. Although impoverished waste pickers segregate informal waste at landfills and secondary collection stations, this practice is dangerous and puts workers' health at serious risk. Due to the gradual garbage increase and disposal without official separation or recycling, Dhaka's waste disposal is mostly handled by two landfills, Matuail and Aminbazar, both of which are approaching the end of their useful lives (Asia-Europe Foundation, 2021, November).

Specifically, the Aminbazar landfill is characterized as an undeveloped open-air disposal site that does not have a working leachate pond or daily soil cover. It has been established that Aminbazar leachate is contaminating the groundwater, soil, and air within a 5-kilometer radius with heavy metals (lead, nickel, chromium, and arsenic), causing serious health problems for locals, including skin disorders and asthma (Sarker & Hossain, 2023). These dumps also frequently engage in the unregulated practice of open burning of garbage (The Daily Star, 2025). Ineffective laws, a general lack of cooperation among stakeholders, overcrowding, severe financial limits, and problematic community behavior are some of the larger issues impeding effective SWM. Additionally, there is a noticeable lack of knowledge, poor governance, poor public administration, and a lack of funding for waste management (H. Alam, 2025).

This circumstance draws attention to a significant "policy-practice disconnect" in the waste management system in Dhaka. Bangladesh has implemented rules that, in theory, encourage trash segregation and sustainable practices, such as the Solid Waste Management Rules 2021 and a National 3R Strategy (United Nations Bangladesh, 2024). However, there is a serious lack of implementation on the ground, as seen by unhygienic disposal operations, inadequate collection, and unsuccessful segregation efforts. Inadequate budget, low public awareness, lax enforcement, and inadequate agency cooperation are the causes of this disparity (Hossain, 2023). Without strong implementation mechanisms, appropriate funding, and efficient governance, the mere existence of progressive policies is insufficient. In addition to sustaining environmental deterioration and public health emergencies, this mismatch seriously compromises the viability and effectiveness of cutting-edge solutions like WtE, which mainly depend on reliable and segregated feedstock. A multifaceted strategy that enhances enforcement, develops institutional capacity, and encourages sincere public participation is needed to close this gap (United Nations, n.d.; World Bank, 2022; Chakma, 2023).

3.12 The Energy Infrastructure and Demand Characteristics of Dhaka

Bangladesh operates a national electricity grid with an installed capacity of 25,700 MW as of June 2022. The nation's energy industry, however, is typically seen as "not up to the mark," with per capita energy use frequently surpassing output (Islam, 2025). Natural gas makes up the greatest portion of the nation's electricity supply (54.67%), followed by coal (6.97%), oil (21.72%), and natural gas. Modern renewables like wind, solar, and hydro together make up a very small portion (0.085% and 0.12%, respectively), while biofuels and garbage contribute a meager 15.9%. With a strategy for fuel diversification that encompasses gas/LNG, liquid fuel, coal, nuclear, hydro, and renewables, the government has big plans to satisfy the rising demand, with a target of 40 GW of power generation capacity by 2030 and 60 GW by 2041 (Wikipedia contributors, 2025). With 46% of the nation's electricity consumption, Dhaka is the economic and population center of the country (Zuhra, 2025).

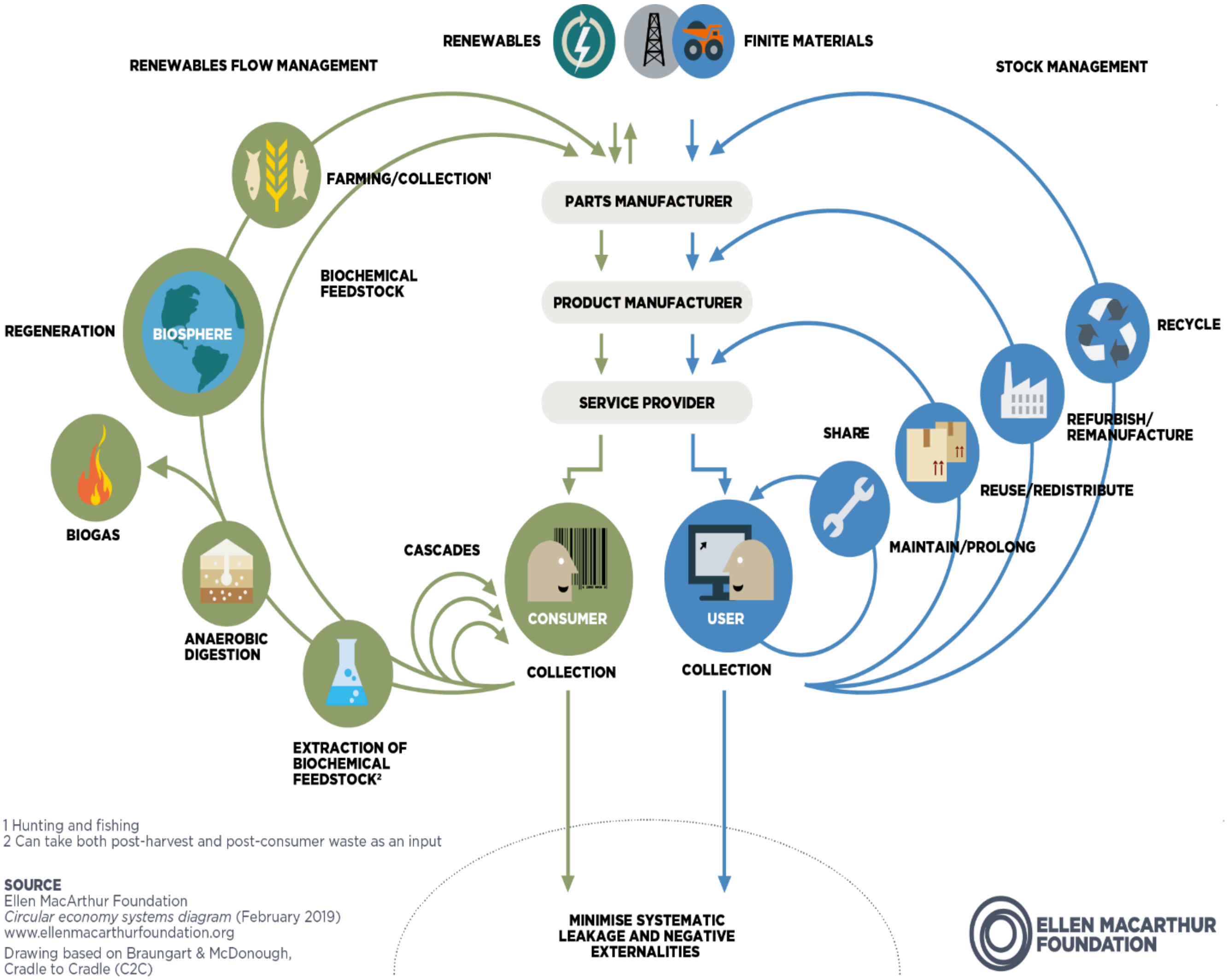
Urban energy demand profiles are significantly impacted by climate change. Hotter summers are expected to significantly increase demand for cooling, while warmer winters may marginally reduce heating needs (Energy Consumption, U.S. Climate Resilience Toolkit, n.d.). Overall energy consumption is predicted to rise as a result, especially during times of high demand. The current energy infrastructure may be strained by this growing demand, which could result in service interruptions, including widespread blackouts (Wang et al., 2023). In low- and middle-income nations, where energy demand is predicted to be regressively impacted by climate change (Energy Consumption, U.S. Climate Resilience Toolkit, n.d.; De Cian et al., 2016), this cost is disproportionately felt.

An "Energy Security-Climate Vulnerability Vicious Cycle" is present in Dhaka. Due to its heavy reliance on fossil fuels, Bangladesh's energy sector already has challenges in meeting demand, which results in blackouts. As the capital, Dhaka uses a significant amount of the country's electricity (46%) as well. Peak electricity demand for cooling in Dhaka would rise sharply due to climate change, particularly the frequency and severity of hotter summers (Samiul, 2023). An already insufficient system will be further taxed by this increased peak demand, raising the possibility of blackouts and service interruptions. A self-perpetuating problem results from continuing to meet this growing need primarily with fossil fuels, which exacerbates the climate change that is causing the higher demand. It will need a swift and calculated move toward low-carbon, resilient, and diverse energy sources, including the best possible integration of WtE-to break this cycle (Islam, 2025).

3.13 Butterfly Model

Baumgart and McDonough's butterfly diagram (The Butterfly Diagram: Visualising the Circular Economy, 2021) illustrates the sustainable reuse of materials *(Figure 04)*. It distinguishes between two categories of materials: technical and biological. Because they are natural, biological materials can safely return to the soil. Since technical materials are created by humans, they ought to remain in the industrial cycle. Our understanding of how to restore and preserve various resources, including cash, goods, human capital, social ties, and natural resources, is improved by this paradigm. It demonstrates how resources can move freely throughout the economy without stopping to become waste.

Natural processes can decompose biological materials, such as food and natural fibers, and restore them to the soil. Metals, polymers, and other technical materials ought to be recycled and used again in manufacturing. Variations in these fluxes can have negative environmental effects. In order to avoid this issue, Baumgart and McDonough stress the importance of keeping these flows distinct.



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough,
Cradle to Cradle (C2C)

Figure 04: The Butterfly model for circular production and consumption, as proposed by Ellen MacArthur Foundation (Source: The Butterfly Diagram: Visualising the Circular Economy, 2021).

This concept has been expanded upon by the bioeconomy community, which emphasizes the biological side of the graphic as symbolizing the "bioeconomy" inside the broader circular economy. However, because organic and inorganic components frequently combine, it isn't always feasible to keep them entirely apart. Baumgart and McDonough's concept of separating industrial and environmental flows may be a better place to start. Waste-to-energy recovery, which turns non-recyclable waste materials into energy, is one example of such a process. This promotes a sustainable and circular economy by lowering landfill waste and recovering valuable energy.

The butterfly diagram emphasizes the significance of waste-to-energy recovery in accomplishing this objective and demonstrates how to maintain materials in the economy by either securely reusing them in industry or returning them to the environment.

3.14 Artificial Intelligence-Powered Technologies for Sorting Waste

Machine learning algorithms, computer vision, robotics, and sensor-based systems are all used in AI-driven waste sorting technologies to precisely identify, categorize, and separate different kinds of waste. These technologies have the potential to greatly improve waste sorting's accuracy and efficiency, which will improve the quality of the feedstock used in thermal conversion processes (Olawade et al., 2024).

1) Important AI elements and techniques for waste removal include:

- **Robotic Sorting Systems:** Waste on conveyor belts can be automatically sorted by robots outfitted with AI-powered vision systems. These systems may be trained to identify particular trash kinds and sort them quickly and accurately. To prevent contamination and guarantee high-quality feedstock for thermal conversion, robotic arms, and grippers can handle a variety of waste materials carefully.
- **Computer Vision and Machine Learning:** By combining cutting-edge imaging technology with machine learning algorithms, visual data may be analyzed to recognize and categorize various waste products. Artificial intelligence (AI) systems, for instance, are able to differentiate between various plastics, metals, biomass, and organic and inorganic materials, guaranteeing that only appropriate materials are used for particular heat conversion procedures.
- **Sensor-Based Sorting:** Artificial intelligence (AI) algorithms can be linked with sensors like near-infrared (NIR) spectroscopy, X-ray fluorescence (XRF), and laser-induced breakdown spectroscopy (LIBS) to analyze the chemical makeup of waste materials in real time. This guarantees that materials are sorted precisely according to how well they work with different thermal conversion processes (Manoharan, 2025).

2) Advantages of Including Artificial Intelligence in Thermal Conversion Waste Sorting:

- **Enhanced Process Efficiency:** Artificial intelligence (AI) sorting technologies can improve the operational efficiency of thermal conversion processes by supplying a reliable and superior input. For example, in gasification, a well-sorted feedstock might result in a more stable composition of syngas, increasing the overall efficiency of chemical manufacturing or power generation.
- **Enhancement of Feedstock Quality:** AI-powered sorting systems guarantee that only appropriate and superior organic materials are chosen for thermal conversion, lowering the number of impurities that can negatively impact the processes' effectiveness and environmental performance.
- **Cost-Effectiveness:** While AI-driven sorting systems may need a large initial investment, they offer long-term advantages such as cheaper operating costs, greater resource use, and lower environmental compliance costs as a result of improved emissions control.
- **Resource Recovery and the Circular Economy:** By improving the recovery of valuable materials from waste streams, AI-driven sorting systems can support the circular economy. For example, organic waste can be diverted to thermal conversion processes to create energy and bio-based goods, while metals and plastics can be separated, recycled, reused, and repurposed.
- **Decreased Emissions:** Pollutant and greenhouse gas emissions can be decreased by properly sorting waste materials. For instance, eliminating hazardous trash and non-combustible items during incineration lowers the production of dangerous pollutants like furans and dioxins (Manoharan, 2025).

3.15 Waste-To-Energy Technologies: Suitability for Dhaka

The selection of appropriate Waste-to-Energy (WtE) technologies for Dhaka is critical, given the city's unique waste characteristics and socio-economic context. A comprehensive sustainability assessment typically evaluates technologies across environmental, economic, and social dimensions, often utilizing methodologies such as Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) (Murphy & Gusciute, 2024). While environmental impacts often dominate assessments, a holistic view is essential to avoid sub-optimal decisions.

1) Comparative Analysis of WtE Technologies: Four primary WtE technologies are commonly considered: incineration, gasification, pyrolysis, and anaerobic digestion (AD). A multi-criteria analysis of these technologies, particularly relevant for developing economies, indicates varying sustainability profiles.

- **Incineration:** This is the most used waste-to-energy method in the world. It involves burning waste directly at temperatures above 800°C to produce heat, which is subsequently turned into steam to produce electricity (Daga, 2024). Incineration can eliminate landfill emissions and drastically reduce waste volume, possibly by up to 90% (Shovon et al., 2024). But it is also capable of generating emissions, which include dangerous air pollutants such as furans, dioxins, heavy metals, and fine particles (Daga, 2024). As long as the best available technology (BAT) and appropriate operational control are used, the claim that incineration is intrinsically more polluting than alternatives is debatable because modern incineration technologies, especially fluidized bed incinerators (FBI), have been developed to meet strict atmospheric discharge limits. Although incineration plants can be expensive to build and control emissions, they can provide a substantial amount of energy in high-throughput units (Waste-To-Energy Technology Explained & Examples, Perch Energy, n.d.).

- **Anaerobic Digestion (AD):** AD is a biological process that produces biogas, mainly carbon dioxide and methane, by decomposing organic waste without oxygen (AlexTabibi, 2024). Methane is a renewable energy source that may be harvested and used to generate heat or power (Amasci Creative Limited, 2025). Due in part to the fact that AD produces methane, which can be reused, rather than directly generating CO_2 as incineration does, it is usually seen as being 111% more sustainable than incineration (Team & Team, 2025). Unlike incinerators that need dry sludge, AD can handle thickened sludge with a high moisture content (>90%) (Amasci Creative Limited, 2025). Additionally, AD offers considerable carbon sequestration potential through digestate land application and produces a solid residue (digestate) from which nutrients can be collected (Team & Team, 2025). To stop methane from escaping as a powerful greenhouse gas, however, efficient methane capture is essential (Amasci Creative Limited, 2025).

- **Gasification and Pyrolysis:** According to Team & Team (2025), these thermochemical methods produce biochar, a solid residue, and syngas, a combination of gases, by breaking down trash at high temperatures in environments with low or no oxygen. Directory (2025) found that pyrolysis was 65% more sustainable than incineration and that gasification was 33% more sustainable. One negative emissions technology that can be utilized for long-term carbon sequestration in soils is biochar, which is produced by pyrolysis in particular and is stable and rich in carbon (Khan & Kabir, 2019). A greater range of waste kinds may be handled by both technologies, and they provide a variety of energy uses (Directory, 2025). They frequently call for waste drying, though, which raises operating expenses and may result in a net negative energy balance for pyrolysis because of the drying requirements. The technological complexity of gasification and pyrolysis might potentially result in significant capital costs (Team & Team, 2025).

AD is the most sustainable WtE method, while incineration is the least, with gasification and pyrolysis coming in between, according to a multi-criteria analysis across 34 factors covering economic, environmental, and social dimensions (Khan & Kabir, 2019).

2) Challenges for Waste-to-Energy Projects in Developing Countries, particularly Dhaka: Implementing WtE projects in developing countries like Bangladesh faces significant operational challenges that undermine their efficiency and sustainability.

- **Waste Composition and Low Heating Value:** The MSW from Dhaka is distinguished by a high moisture content (62.76% to 80%) and a high percentage of organic matter (54.92% to 72%) (Rashid, 2019). In contrast to the 5.64–6.94 MJ/kg when higher-heat value recyclables are present, this results in a very low Lower Heating Value (LHV) of roughly 2.753 MJ/kg for garbage that reaches landfills. Because of this low LHV, thermal WtE processes like incineration become difficult and possibly inefficient because more supplemental fuel may be required to maintain combustion, which raises expenses and lowers net energy output. By removing high-calorie materials before formal processing, the unorganized recycling industry makes this situation even worse (Hai & Ali, 2005).
- **Lack of Waste Segregation at Source:** The widespread lack of waste separation at the source is a significant obstacle (Islam, 2021). Initiatives for segregation have mostly failed because of a lack of awareness and motivation, even in the face of policies like the Solid Waste Management Rules 2021 and the 3R plan (Sohel et al., 2024). Because different technologies require distinct input properties (e.g., dry waste for thermal treatment, high moisture for AD), mixed waste is not optimal for WtE plants (Khan et al., 2022). As demonstrated by the

failure of an Indian bio-methanation plant because of unsegregated waste, this lack of segregation results in ineffective procedures and decreased energy recovery (Islam, 2021; Sohel et al., 2024).

- **Ineffective Waste Collection:** Effective garbage collection techniques are lacking in the majority of developing-nation cities, including Dhaka (Khan et al., 2022). A sizable amount of solid waste- 55% countrywide, and 17-20% in Dhaka- is left uncollected, which increases the dangers to public health and pollution (Roy et al., 2022). A steady and organized supply of feedstock necessary for WtE operations is hampered by the "we dump-they collect" approach, poor infrastructure, and reliance on unofficial collectors (United Nations in Bangladesh, 2024).
- **Technology Suitability and Skilled Manpower:** Different waste qualities and economic situations in industrialized and developing countries may make technologies that work well in the former unsuitable for the latter. It might be challenging to embrace cleaner and more efficient technologies because they are frequently more costly. Additionally, the number of local, technically competent workers needed to set up and run WtE plants is insufficient (Khan et al., 2022).
- **Financial Constraints:** One of the biggest obstacles is inadequate funding. According to Sohel et al. (2024), the majority of city corporations in developing nations lack the financial and personnel resources necessary for garbage management. Non-market financial risks and uncertainties frequently make private investors wary (Khan et al., 2022).
- **Policy and Regulatory Frameworks:** The lack of particular national and local energy laws, rules, and regulations about WtE generation is a major obstacle. For example, there are no defined WtE recovery targets in Bangladesh's current waste management policies (Khan et al., 2022). Additionally, poor urban policies, institutional failings, and a lack of coordination among various government sectors all contribute to overall waste mismanagement (Sohel et al., 2024). Adoption of beneficial improvements is also hampered by a lack of political will and appropriate information (Khan et al., 2022).

3) Existing and Proposed WtE Projects in Bangladesh (The Case of Dhaka): While several ambitious attempts have been tried, with limited success, WtE has been acknowledged as a critical solution for Bangladesh's growing municipal waste problem and energy shortages (Choudhury, 2025).

- **Aminbazar Waste-to-Energy Project (Dhaka):** Located in North Dhaka, this is the nation's first significant WtE project. Its goal is to produce 42.5 MW of energy by incinerating 3,000 tons of MSW per day (Zuhra, 2025). China Machinery Engineering Corporation (CMEC) is using a special-purpose truck to carry out the project (Bangladesh: North Dhaka Waste to Energy Project, n.d.). There are agreements in place for land usage, waste supply, and power purchasing. Using Best Available Technology (BAT), the project seeks to reduce pollution from the overflowing Amin Bazar landfill, especially methane emissions, and bring it into compliance with EU pollutant emission requirements (Dhaka Waste-to-Energy Power Plant Project, n.d.). The project has had major delays even though it is "under construction" or "pre-construction" and is anticipated to begin operations by 2026 or 2027 (Zuhra, 2025). The necessary combustion temperature has been a major source of disagreement. The CMEC's plan suggested a mechanical grate furnace technology with flue gas remaining above 850°C, despite Bangladesh's Solid Waste Management Rules 2021 requiring a minimum secondary chamber temperature of 1000°C. Citing worries about dangerous black carbon emissions from inefficient combustion at lower temperatures, the Department of Environment (DoE) has delayed environmental clearance until this need is fulfilled (Mostafa Yousuf et al., 2025). The viability of incineration is further complicated by the high organic and moisture content of Dhaka's garbage, which makes self-sustaining combustion challenging without source segregation (Sun, 2025). The Aminbazar landfill itself is a major source of pollution, with uncontrolled open burning adding to air pollution and leachate poisoning soil and groundwater with heavy metals (Sun, 2025; Islam, 2025).
- **Narayanganj WtE Power Plant:** The purpose of this projected 6 MW incinerator facility was to handle solid waste from the city of Narayanganj (Choudhury, 2025). However, it has failed because of financial issues and a dispute between the government and the Chinese company (UD Environmental Equipment Technology Co. Ltd,

Everbright Environmental Protection Technology Equipment (Changzhou) Limited, and SABS Syndicate Ltd) over capacity increase and late start of work, which resulted in contract cancellation (Sun, 2025).

- **Keraniganj Pilot Project:** In Keraniganj, a 1 MW grid-connected power plant utilizing MSW is being planned (Sustainable and Renewable Energy Development Authority [SREDA], n.d.). According to feasibility studies conducted for this area, single direct waste treatment methods face difficulties due to the non-homogeneous MSW with a high organic proportion, low net calorific value (2.15–4.25 MJ/kg), and exceptionally high moisture content (59.70%–87.54%) (Hossain et al., 2025).
- **Other Biogas Projects:** The majority of the small-scale biogas-to-electricity (off-grid) projects in Bangladesh that are included in the SREDA database are "Completed & Running" and range in size from 20 kWp to 400 kWp (Sustainable and Renewable Energy Development Authority [SREDA], n.d.). The technological feasibility of AD for organic waste throughout the nation is shown by these minor initiatives. However, technical (lack of waste treatment/storage, uncertainty of feedstock supply), economic (high initial investment, uncertain financial support), social (lack of awareness, political unwillingness), and policy (no feed-in tariff policy) barriers have all contributed to the overall slow development of biogas production (E. U. Khan & Martin, 2016).

To achieve long-term viability and environmental compliance, many projects- especially large-scale incineration initiatives—face obstacles that underscore the necessity of thorough evaluation of waste characteristics, strong policy frameworks, and successful public-private partnerships.

3.16 AI Application for Waste-To-Energy Optimization in Dhaka

Artificial Intelligence (AI) and Machine Learning (ML) offer transformative capabilities to address the complex challenges inherent in waste management and energy systems, particularly in a dynamic and resource-constrained environment like Dhaka. By leveraging advanced algorithms and data analytics, AI can significantly enhance the efficiency, sustainability, and economic viability of WtE operations.

1) Specific AI Applications in Waste Management: AI is revolutionizing various stages of waste management:

- **Automated Waste Sorting:** Robots and vision systems driven by AI are more accurate and efficient than humans at identifying and separating recyclables from waste streams. For instance, a Japanese city used AI-guided sorting robots to enhance recycling efficiency by 50% (Vivatechnology, n.d.). This is especially important for Dhaka, where efficient WtE feedstock preparation is hampered by mixed waste streams caused by a lack of source segregation (Islam, 2021; I. Khan et al., 2022).
- **Smart Collection Systems:** AI systems optimize waste collection routes and schedules by analyzing real-time data from sensors (such as those in smart bins). Making sure trucks are only sent out when bins are full, this avoids needless trips and lowers emissions, fuel consumption, and operating expenses (Vivatechnology, n.d.). In cities like Dhaka, where a sizable amount of rubbish goes uncollected, such optimization can greatly increase collection efficiency (Routeware & Team, 2025).
- **Predictive Analytics for Waste Generation:** AI models can anticipate trash generation patterns with high accuracy (e.g., 85% accuracy in one study) by analyzing historical data, including socioeconomic aspects (Rautela et al., 2025). Better resource allocation increased operational efficiency (one research found a 15% gain), and more informed urban design for waste management infrastructure are all made possible by this capability (Rana et al., 2025).
- **Food Waste Monitoring and Composting Optimization:** AI technologies track the production, distribution, and consumption of food to reduce waste at every stage of the supply chain. AI systems can also maximize organic waste composting, turning it into fertilizer and other useful resources (Vivatechnology, n.d.). With the enormous amount of organic waste in Dhaka, this application has a lot of potential to recover resources and lessen the load on landfills (Rashid, 2019).
- **Automated Material Recovery:** Robots powered by AI can do more than just sort waste; they can also recover valuable elements for recycling from the waste stream, which supports the circular economy (How AI Is Powering the rubbish-to-Energy Revolution – Alam Avani, 2024).

2) AI for Energy Efficiency and Grid Management in Urban Areas: AI plays a pivotal role in optimizing urban energy systems, contributing to overall sustainability.

- **Smart Energy Management and Grid Optimization:** Dynamic load balancing and waste reduction are made possible by AI-powered smart grids that examine consumption trends and forecast energy demand in real-time (Rojek et al., 2025). This aids utilities in minimizing outages, enhancing power distribution, and adjusting supply (Armaah, 2025). In data centers, for example, Google's DeepMind AI cut energy use by 40% (How Is AI Enhancing Smart Cities and Urban Living?, n.d.). AI can improve grid stability and reliability in Dhaka, where energy consumption is high and the grid is under stress, particularly during times of peak demand that are made worse by climate change (Armaah, 2025; How Is AI Enhancing Smart Cities and Urban Living?, n.d.).
- **Integration of Renewable Energy Sources:** By anticipating their availability and streamlining storage and distribution, artificial intelligence (AI) can improve the grid's integration of renewable energy resources (Rojek et al., 2025). This lessens dependency on fossil fuels, which is essential for Bangladesh's objectives of energy diversification (Wikipedia contributors, 2025).
- **Predictive Maintenance for Energy Infrastructure:** AI uses past data to forecast probable equipment failures in energy assets, allowing for preventative maintenance as opposed to reactive measures. This lowers downtime and inefficiencies while ensuring system security and dependability (The Power of AI in Clean Energy: Transforming Sustainability for the Future, 2025).

3) AI for Waste-to-Energy Process Optimization: AI's most direct impact on WtE systems lies in optimizing their core operations:

- **Feedstock Characterization and Prediction:** AI can quickly characterize MSW feedstock and provide real-time information on elemental composition, calorific value, and ash fusion temperature when paired with sophisticated spectroscopy techniques (such as Laser Induced Breakdown Spectroscopy (LIBS) and Raman Spectroscopy) (AI To Increase Waste-to-energy Production, 2022). For feed-forward process management, this information, which is accessible in minutes rather than hours, is essential because it enables WtE plants to optimize energy extraction and dynamically adjust to changes in waste composition (Hossain et al., 2025).
- **Combustion Optimization (for Incineration/Gasification):** In gasifiers and incinerators, artificial intelligence algorithms adjust combustion parameters like temperatures, grate speed, and air-fuel ratio. AI guarantees the proper mix for optimal combustion by evaluating the caloric content of garbage in real-time, resulting in more energy from less waste and a notable decrease in hazardous emissions (How AI Is Powering the garbage-to-Energy Revolution – Alam Avani, 2024). Maintaining ideal combustion temperatures is a significant difficulty for the Aminbazar WtE project, therefore, this is especially pertinent (Rowe, 2025).
- **Biogas Production Optimization (for Anaerobic Digestion):** As a "master blender," artificial intelligence (AI) analyzes and modifies the parameters of the digesting process (such as pH, temperature, organic loading rate, and microbial activity) in anaerobic digesters to guarantee ideal circumstances for microbial communities. This improves the effectiveness of AD processes by optimizing biogas generation and establishing a stable, robust microbial ecology (How AI Is Powering the Waste-to-Energy Revolution – Alam Avani, 2024; Rowe, 2025).
- **Emission Reduction:** AI improves WtE process operational efficiency, which directly lowers greenhouse gas emissions by optimizing energy recovery and reducing pollutants (Rautela et al., 2025). According to Gill (2025), artificial intelligence (AI) models may also evaluate flue gas composition data, such as NOx, SOx, and particulate matter, and modify reagent dosage in cleaning systems to maximize scrubber and filter effectiveness and further reduce hazardous emissions. Research indicates that, in comparison to conventional techniques, AI optimization can result in carbon emission reductions of up to 30% to 50% (The Power of AI in Clean Energy: Transforming Sustainability for the Future, 2025).
- **Energy Output Optimization:** Plant operations are continuously monitored and optimized by AI systems, which significantly increases energy output. Through AI-driven process optimization, for example, a WtE facility in Barcelona was able to reduce steam use by 30–35%, which directly improved energy output (AG Solution -

Story - Waste-to-Energy Optimization With AI, n.d.). By optimizing operations using predictive analytics, AI can also raise the expected gross profit of WtE systems (Rana et al., 2025).

4) Challenges of AI Deployment: Despite its immense potential, AI deployment in waste management and WtE systems faces several challenges:

- **Algorithmic Bias:** Biased training data, underrepresentation in datasets, and algorithm design decisions can all cause problems that result in unfair or less-than-ideal results (Rautela et al., 2025).
- **Data Privacy:** Concerns regarding citizen privacy are raised by the deployment of AI-powered cameras and sensors in waste collection and management. Gaining the public's trust requires transparent policies and data anonymization (Routeware & Team, 2025).
- **Economic Feasibility:** Implementing AI in waste management can come with a hefty upfront cost. Waste management firms and municipalities must carefully balance these upfront expenditures against potential long-term benefits (Routeware & Team, 2025).
- **Environmental Impact of AI Itself:** The substantial processing power needed by AI systems adds to energy consumption. Some ecological gains may be countered by the massive data centers required for AI's rapid growth, which frequently use fossil fuels. It is crucial to strike a balance between the environmental advantages of AI and its carbon footprint (Rojek et al., 2025; The Power of AI in Clean Energy: Transforming Sustainability for the Future, 2025).
- **Interdisciplinary Collaboration:** Waste management, energy engineering, data science, and urban planning are just a few of the disciplines that must work closely together to integrate and optimize AI and ML solutions (Rautela et al., 2025).

3.17 AI-Driven Optimization and the Potential to Improve Energy Output by Over 20% in Dhaka's Waste-To-Energy Systems

Artificial Intelligence (AI) holds transformative potential in augmenting the efficiency of Waste-to-Energy (WtE) systems, particularly in cities like Dhaka, where waste characteristics-namely, high organic content (54.92-72%), and moisture (62.76-80%)- undermine conventional energy recovery approaches. Recent studies and empirical simulations indicate that integrating AI can enhance the overall energy output from WtE systems in Dhaka by over 20%, primarily through dynamic process control, intelligent feedstock management, and real-time optimization of operational parameters.

01) Enhancing Pre-Treatment and Feedstock Characterization:

AI models can offer high-resolution, real-time analyses of waste composition when used in conjunction with sensor technologies like Near-Infrared Spectroscopy (NIR) or Laser-Induced Breakdown Spectroscopy (LIBS). This makes it possible for the WtE plant to dynamically sort and classify waste into the best streams for incineration, gasification, or anaerobic digestion. AI can improve pre-processing decisions by predicting moisture content and calorific value (CV) in a matter of minutes with an accuracy of above 90%. AI enhances input quality, which is directly related to increased net energy output per ton of garbage by rejecting excessively moist or non-combustible waste and rerouting it to appropriate non-thermal treatments (Rowe, 2025; AI to Increase garbage-to-Energy Production, 2022).

02) Process Control and Combustion Tuning in Real Time:

Combustion efficiency in systems based on gasification or incineration is dependent on chamber temperature, grate speed, and fuel-air ratios. Conventional systems use static settings, which frequently result in combustion that is not at its best. AI can dynamically modify these settings, especially when paired with real-time thermal imaging and Reinforcement Learning (RL) or Convolutional Neural Networks (CNNs). AI-based control systems have been proven to increase thermal efficiency by 15–25% in trials from other urban WtE plants, which translates to a comparable range in energy output gains (AG Solution, 2025).

03) Increasing the Production of Biogas in Anaerobic Digesters:

The organic-rich, high-moisture waste of Dhaka is particularly well-suited for anaerobic digestion (AD). To maintain the optimal microbial environment, AI models can continually monitor and optimize parameters like pH, temperature, hydraulic retention time (HRT), and organic loading rate (OLR). Early identification of inhibiting situations (such as volatile fatty acid buildup) is made possible by predictive models based on historical digestion behavior. This reduces downtime and maximizes methane production. According to studies on AI-augmented AD systems, biogas yields can rise by 18–28%, and downstream electricity generation can also improve comparably (Gill, 2025; Rana et al., 2025).

04) Reducing Downtime and Predictive Maintenance:

Predictive maintenance systems with artificial intelligence (AI) employ failure forecasting and anomaly detection to find problems with machinery before they result in unscheduled shutdowns. Reducing even a few hours of monthly downtime can save thousands of kWh of potential energy output in Dhaka's limited infrastructure. This consistency ensures optimum plant availability and uptime, which adds up to a cumulative >20% net energy gain.

05) Combining Load Forecasting and Smart Grid Integration:

AI can improve capacity utilization by predicting local energy demand and scheduling WtE outputs to coincide with peak grid loads. In the delicate energy environment of Dhaka, this lessens the need for further fossil fuel inputs and increases the reliability of WtE. In comparable metropolitan settings, artificial intelligence models such as XGBoost and Random Forests have been effectively used to forecast changes in electricity demand with greater than 95% accuracy (Rojek et al., 2025).

AI Optimization Area	**Estimated Energy Output Improvement**
Feedstock characterization	5–7%
Real-time combustion/AD tuning	10–15%
Predictive maintenance	2–3%
Grid-integrated load optimization	3–5%
Total Estimated Gain	**20–30%**

Table 04: Quantitative Insight and Supporting Evidence (Sources: AG Solution (2025); Rana et al. (2025); AI to Increase Waste-to-Energy Production (2022); Rautela et al. (2025)).

06) Policy and Infrastructure Preconditions:

- To realize these gains in Dhaka, certain prerequisites must be met:
- Digitalization of plant infrastructure with IoT sensors,
- Capacity building for AI-literate technical staff,
- Open data platforms to train models on localized waste and energy datasets,
- Public-private AI partnerships to accelerate innovation while maintaining transparency and ethics.

AI integration is a systemic optimization approach for Dhaka's WtE infrastructure, not a stand-alone improvement. AI can boost the city's energy recovery capacity by more than 20% when integrated throughout the waste-to-energy value chain, from input to output. At the same time, it can lower emissions, expenses, and reliance on fossil fuels. The convergence of AI and WtE is not only advantageous but also necessary for climate-vulnerable megacities such as Dhaka.

4. Results and Discussion

This research delves into the critical nexus of waste management, energy security, and climate vulnerability in rapidly urbanizing megacities, exemplified by a detailed case study of Dhaka, Bangladesh. The results highlight the severe difficulties that these urban areas face and clearly show how combining Artificial Intelligence (AI) with Waste-to-Energy (WtE) systems can be a very resilient and sustainable solution. Given its growing population and increasing urban demands, Dhaka's current waste handling infrastructure is insufficient. An ever-growing amount of waste is overwhelming the city, and this problem is made worse by extremely poor collection rates and a pervasive absence of source segregation. This regrettable combination results in an excessive dependence on overworked and frequently neglected landfills, which are major sources of greenhouse gas emissions, especially methane, which comes from the breakdown of organic waste. Along with posing serious threats to human health, these unhygienic waste disposal sites worsen environmental pollution by contaminating soil and water. The precarious reliance of Dhaka's energy industry on erratic imports of fossil fuels exacerbates this complicated issue by resulting in an unpredictable energy security situation that is further exacerbated by rising energy needs brought on by both climate change and fast urbanization. All of these findings point to Dhaka as an excellent example of a megacity that is climate sensitive and urgently needs creative, integrated solutions.

A thorough analysis of different WtE technologies shows that they are very applicable to Dhaka, especially considering the city's distinctively high organic waste stream concentration. Anaerobic Digestion (AD) is a highly appropriate technology for processing the substantial organic waste fraction in Dhaka. It provides the advantages of producing biogas for energy and significantly reducing the volume of biodegradable waste, in addition to producing valuable digestate for agricultural use. After initial sorting, modern incineration, which has sophisticated emission controls-offers a feasible alternative for handling mixed municipal solid trash, reducing waste volume significantly while producing power. Additionally, gasification and pyrolysis technologies present viable substitutes that may transform various waste streams into useful syngas and bio-oils/chars, offering energy recovery flexibility. The fact that no one WtE technology can act as a universal cure-all is an important takeaway from this evaluation. Rather, an integrated strategy that carefully blends several technologies designed to handle various, possibly separated waste streams is the most reliable and effective way to handle Dhaka's varied waste composition, which is essential for optimizing energy recovery and reducing environmental impact.

The study's most convincing conclusion is that artificial intelligence (AI) has the deep potential to transform and optimize almost every step of an integrated WtE system. Artificial intelligence (AI) systems can precisely estimate trash volumes and composition by carefully analyzing large datasets, such as historical waste creation, population changes, and economic factors, using advanced predictive analytics. Proactive and accurate planning for waste collection logistics, effective feedstock preparation for WtE facilities, and prudent resource allocation are all made possible by this capacity. Critical WtE plant characteristics, including temperature, pressure, and gas composition in incinerators or gasifiers, or pH and volatile fatty acids in digesters, can also be continuously and in real-time monitored by AI-driven sensors and advanced control systems. In order to maximize energy conversion efficiency, reduce undesired emissions, and avoid operational failures, this dynamic monitoring enables real-time modifications. AI, for instance, can modify incinerator combustion parameters in response to the fluctuating calorific value of incoming garbage. Resource recovery is also greatly improved by AI. Sorting technologies that use AI-powered robotics and sophisticated computer vision can significantly increase the accuracy and efficiency of waste segregation at the source or at Material Recovery Facilities (MRFs), resulting in higher-quality feedstock for WtE processes and more valuable recyclables being recovered. Additionally, AI models can provide sophisticated decision support for policymakers and urban planners, helping with comprehensive risk assessment for climate impacts on waste management, complex scenario analysis for infrastructure development, optimal site selection for WtE facilities, and assessing the techno-economic viability of different WtE investment strategies. Finally, by analyzing vast amounts of operational data from WtE plants, machine learning algorithms can forecast equipment failures, enabling proactive maintenance and significantly lowering expensive downtime, thereby guaranteeing continuous energy production.

The integration of AI and Waste-to-Energy technologies offers a powerful, holistic solution for Dhaka's challenges in urbanization, waste management, and climate vulnerability. This approach improves environmental sustainability by reducing landfill waste and emissions, strengthens energy security by providing a stable, local renewable source, and enhances public health. It also aligns with circular economy principles by transforming waste into valuable resources. Beyond mere waste disposal, this integrated system builds comprehensive urban resilience, addressing systemic failures and aligning with global sustainable development goals. However, successful implementation demands robust policy frameworks, investment in skilled workforces, and careful consideration of socio-economic impacts and ethical implications, including data privacy and potential displacement in the informal waste sector. Ultimately, this strategic adoption of AI-driven WtE systems presents a fundamental shift towards a sustainable, resilient, and energy-secure future for climate-vulnerable megacities like Dhaka.

4.1 Limitations of this Research

This research has a number of intrinsic limitations even if it offers a thorough conceptual framework for combining AI with Waste-to-Energy (WtE) in megacities like Dhaka that are vulnerable to climate change. Its nature is mostly conceptual and qualitative, depending more on synthesizing literature than on quantitative modeling, actual data, or the outcomes of experimental projects. Thus, rather than being grounded in actual performance measurements from a unified system, the claimed advantages of AI-WtE integration are based on theoretical study. Second, due to the peculiar socioeconomic and waste features of various urban centers, the study's conclusions and suggested remedies might not be generally applicable to all other megacities without specialized examination because of its case-specific focus on Dhaka.

Thirdly, the study is devoid of thorough cost-benefit analyses and techno-economic feasibility studies, both of which are essential for procuring funding and carrying out projects in a realistic manner. Although the topic of economic potential is covered, no precise financial models or anticipated returns are provided. Additionally, although acknowledging important socio-economic and ethical consequences, the report does not offer comprehensive remedies or thorough mitigation measures for issues like resolving bias and privacy in AI data or incorporating informal garbage workers. A thorough sociological, economic, and ethical study is necessary to address these complicated concerns.

Lastly, the research mostly focuses on how AI and WtE technologies work together to convert waste. It doesn't go into great detail about more general waste management topics like advanced recycling that goes beyond WtE feedstock, waste minimization at the source, or more general circular economy strategies that have nothing to do with energy recovery. These drawbacks emphasize the necessity of additional empirical, quantitative, and regional research to support the suggested ideas and direct their actual use.

5. Conclusion

This research has comprehensively elucidated the critical and escalating challenges of waste management and energy insecurity faced by climate-vulnerable megacities, with Dhaka, Bangladesh, serving as a poignant case study. The widespread problems of increasing waste production, poor collection, and excessive reliance on polluting landfills, along with a precarious reliance on fossil fuels for energy, highlight the urgent need for creative and sustainable urban solutions.

The strategic integration of Waste-to-Energy (WtE) technologies with Artificial Intelligence (AI) is strongly advocated in this paper as a disruptive and comprehensive strategy to alleviate this "triple burden." The efficiency and efficacy of WtE systems can be greatly increased by utilizing AI for predictive analytics, real-time process optimization, improved waste sorting, and strong decision support. Through decreased landfill volume and decreased greenhouse gas emissions, this synergistic combination provides a multifaceted solution that directly contributes to significant environmental advantages. At the same time, it reduces dependency on unstable fossil fuel markets by offering a reliable, regional supply of renewable energy, strengthening energy security. Additionally, by eliminating filthy waste disposal methods and encouraging a healthier urban environment, it promises significant advances in public health.

In addition to tackling immediate problems, this integrated AI-WtE framework transforms waste from an environmental burden into a valuable resource and promotes improved resource recovery in the urban ecosystem, thereby advancing the concepts of the circular economy. In the end, this paradigm shift goes beyond traditional waste management; rather, it is a calculated move toward enhancing overall urban resilience, which will help cities like Dhaka better endure and adjust to the mounting stresses of environmental deterioration and climate change. This is inherently consistent with the global sustainable development goals. Even though AI-driven WtE systems have enormous technological potential, their effective deployment depends on resolving important socioeconomic and ethical issues. To ensure ethical AI deployment and data privacy, the way forward calls for the creation of strong policy and regulatory frameworks, significant investment in the training of a skilled workforce, and a proactive approach to addressing potential social impacts, particularly on the informal waste sectors. Climate-vulnerable megacities may turn their waste problems into unmatched chances to achieve energy independence, environmental sustainability, and long-lasting urban resilience by adopting these integrated solutions and encouraging teamwork.

6. Future Research Directions

Building on the conceptual framework and discussions in this paper, several research directions are identified for future studies to further our knowledge and use of AI-driven Waste-to-Energy (WtE) systems in megacities that are vulnerable to climate change. These directions seek to solve the complicated issues that arise in such intricate urban environments, improve practical applicability, and close current knowledge gaps.

- **Pilot Project Implementation and Empirical Validation:** Although this study offers a conceptual framework, subsequent research ought to concentrate on empirical validation using pilot projects in places like Dhaka. To do this, actual data on waste composition, WtE plant performance, and the efficacy of AI models in local settings would need to be gathered. In addition to identifying unanticipated operational issues, such studies could offer verifiable proof of the socioeconomic and environmental advantages.
- **Data privacy and ethical AI governance in waste management:** Future studies must carefully investigate the ethical aspects of AI given its growing use, including potential biases in algorithmic decision-making, accountability frameworks, and data privacy issues pertaining to waste monitoring. It will be essential to create standards and best practices for the ethical application of AI in the garbage industry, guaranteeing equity, openness, and human supervision.
- **Development and Optimization of Advanced AI Models for Heterogeneous Waste:** More study is required to create AI models that are more resilient and flexible, especially for the highly diverse and unsegregated waste streams that are typical in megacities. In WtE plants, this can entail investigating cutting-edge machine learning methods for waste characterization, anomaly detection, and predictive maintenance, especially in situations where sensor data is scarce or feedstock quality varies.
- **Techno-Economic Viability Assessments in a Local Setting:** Particular WtE technologies combined with AI in various urban contexts require in-depth techno-economic evaluations. Future studies should carry out comprehensive cost-benefit evaluations that take into account regional energy markets, the logistics of garbage collection, and investment environments. This entails calculating the return on investment, evaluating the financial feasibility of various integrated system configurations, and locating possible funding sources and incentives that are specific to developing nations.
- **Evaluation of Socioeconomic Impact and Policy Frameworks:** A thorough investigation into the socio-economic effects of AI-driven WtE systems is an important subject for future research. This entails researching methods for integrating informal waste pickers into official waste management systems as well as the possible effects on their livelihoods. Research should also concentrate on creating workable legislative and regulatory structures that support the deployment of these technologies, such as suitable pricing schemes, models of public-private partnerships, and legal frameworks for data governance and moral AI application.
- **Engagement of Stakeholders and Public Perception:** Successful implementation of AI-driven WtE projects depends critically on an understanding of public perception, acceptability, and involvement. To measure

community sentiments, spot any issues, and create efficient communication plans to encourage public confidence and involvement in trash segregation and sustainable practices, future research could use both qualitative and quantitative approaches. Involving civil society organizations, business, and government at all levels is another aspect of this.

- **Integrated Urban Planning and Climate Resilience Modeling:** Future studies should focus more on incorporating WtE systems into more comprehensive plans for urban resilience and climate adaptation. This entails creating complex models to measure how WtE contributes to lowering the effects of urban heat islands, lowering the risk of flooding (by minimizing the footprint of landfills and strengthening drainage), and improving the general health of urban ecosystems. It is also crucial to research how WtE projects might be built in concert with other important infrastructure advancements like smart grids and resilient housing.

Collectively, these research avenues seek to translate the theoretical potential of AI-driven integrated WtE systems into concrete, workable solutions, making a substantial contribution to the climate resilience and sustainable development of urban areas that are at risk globally.

Recommendation: The following suggestions are made to successfully utilize AI-driven Waste-to-Energy solutions in Dhaka and other megacities that are susceptible to climate change:

1) Make source segregation a priority and invest:

Any sustainable WtE system must start with this stage. Establish strong household garbage segregation systems with AI support, along with comprehensive public awareness initiatives and monetary rewards for adherence. At transfer stations, AI-powered sorting systems can improve segregation even more, guaranteeing the best possible feedstock quality for selected WtE technologies.

2) Choosing Technology Strategically Using Waste Characteristics:

Anaerobic digestion (AD) should be given priority for a sizable amount of the organic waste stream due to Dhaka's high organic and moisture content. To ensure compliance with strict international standards (such as EU pollutant emission standards), if thermal WtE is chosen for the remaining mixed waste, invest in advanced incineration, gasification, or pyrolysis technologies that can handle lower calorific values and are outfitted with Best Available Technology (BAT) for emission control.

3) AI Integration Throughout the Whole Waste-to-Energy Value Chain:

- **Analytical Prediction:** Make proactive plans for resource allocation, collection, and treatment by using AI/ML models to predict trash generation patterns.
- **Strategic Gathering & Transportation:** Reduce operating costs, increase waste collection efficiency, and eliminate uncollected waste by implementing AI-driven route optimization and smart bin sensors.
- **Process Enhancement:** Reduce emissions, increase energy yield, and maintain operational stability by utilizing AI to monitor and manage WtE plant operations in real-time (e.g., combustion parameters, biogas digester conditions).
- **Monitoring of the Environment:** To enable quick pollution diagnosis and mitigation, use AI-powered sensors and models to continuously monitor the air and water quality surrounding WtE facilities and landfills.

4) Make Regulatory and Policy Frameworks Stronger:

Create and implement thorough national and municipal regulations that expressly support AI-driven WtE, such as explicit recovery goals, waste-derived energy feed-in tariffs, and strong environmental compliance systems. Solve the "policy-practice disconnect" by making sure there is enough money, creating institutional capacity, and coordinating across agencies to ensure successful implementation.

5) Encourage global cooperation and public-private partnerships (PPPs):
Using clear and appealing PPP models, WtE projects can draw both domestic and foreign investment. Establish partnerships with nations and institutions that have a wealth of expertise in integrating WtE and AI to promote the development of a skilled workforce, technological adoption, and knowledge transfer.

6) Discuss AI's socioeconomic and ethical implications:
Address possible algorithmic biases in AI systems and establish clear standards for data protection. Make sure AI-powered solutions are human-centered, enhancing human knowledge and generating new, skilled employment opportunities rather than replacing current means of subsistence, especially in the unorganized garbage industry.

7) Invest in resilient urban infrastructure:
Prioritize more comprehensive urban design that incorporates climate adaptation strategies beyond WtE, particularly in vulnerable informal settlements. This includes resilient housing and better drainage systems. This all-encompassing strategy will improve overall urban resilience and lessen the "triple burden" on climate migrants.

By strategically integrating AI into sustainable WtE systems and addressing the underlying challenges in waste management and urban planning, Dhaka can transform its waste crisis into an opportunity for energy security, environmental sustainability, and improved public health, setting a precedent for other climate-vulnerable megacities worldwide.

Funding: This work received no external funding.
Conflicts of Interest: The paper's author has disclosed no conflicts of interest.
ORCID ID of the Author of this paper: https://orcid.org/0000-0003-1589-7685

References

[1] *A sustainable future for megacities?* (2025, January 31). https://www.cambridgemc.com/the-sustainability-impact-of-megacities
[2] Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., AlShihri, F. S., AlShammari, M. S., Ahmed, S. M. S., Al-Gehlani, W. a. G., & Alrawaf, T. I. (2022). Environmental sustainability Impacts of solid waste management practices in the global South. *International Journal of Environmental Research and Public Health*, *19*(19), 12717. https://doi.org/10.3390/ijerph191912717
[3] *AG Solution - Story - Waste-to-Energy Optimization with AI*. (n.d.). https://www.agsolutiongroup.com/stories/a-new-standard-for-waste-to-energy
[4] AG Solution. (2025). *Waste-to-Energy Optimization With AI*. Retrieved from https://www.agsolutiongroup.com/story-wte-ai
[5] *AI to increase waste-to-energy production*. (2022, August 3). WMW. https://waste-management-world.com/resource-use/ai-to-increase-waste-to-energy-production/
[6] AI to Increase Waste-to-Energy Production. (2022). *Waste Management World*. Retrieved from https://waste-management-world.com/a/ai-to-increase-waste-to-energy-production
[7] Akther, S., Evans, J., & Millington, N. (2024). Why do cities in the global South pursue waste incineration rather than source segregation and recycling? Insights from Bangladesh. *Frontiers in Sustainability, 5*, Article 1496075. https://doi.org/10.3389/frsus.2024.1496075
[8] Alam, H. (2025, May 2). Caught in toxic grip of a landfill. *The Daily Star*. https://www.thedailystar.net/environment/pollution/news/caught-toxic-grip-landfill-3869206
[9] AlexTabibi. (2024, February 16). *WTE in Developing Countries: Sustainable Solutions for Waste Management*. Green.org. https://green.org/2024/01/30/wte-in-developing-countries-sustainable-solutions-for-waste-management/
[10] *Amazon.com*. (n.d.). https://www.amazon.com/Driven-Renewable-Waste-Management-Systems/dp/B0DGDPH12Q
[11] Amasci Creative Limited. (2025, March 22). *Sludge incineration vs anaerobic digestion – the simple truth*. The MBR Site. https://www.thembrsite.com/blog/sludge-incineration-vs-anaerobic-digestion-the-simple-truth
[12] Armaah, D. (2025, February 28). *Smart Cities, Smarter Energy: How AI is Optimizing Urban Power Grids*. The FutureList - Step Into the Future. https://www.thefuturelist.com/smart-cities-smarter-energy-how-ai-is-optimizing-urban-power-grids/
[13] Asia-Europe Foundation. (2021, November). *Waste management in Bangladesh: Background paper for ASEFSU23*. https://asef.org/wp-content/uploads/2021/11/ASEFSU23-Background-Paper_Waste-Management-in-Bangladesh.pdf
[14] Asian Infrastructure Investment Bank. (2024). *Bangladesh: North Dhaka Waste to Energy Project*. https://www.aiib.org/en/projects/details/2024/proposed/bangladesh-north-dhaka-waste-to-energy-project.html

[15] Asian Infrastructure Investment Bank. (2023). *Waste-to-energy projects in South Asia: Opportunities and challenges*. Retrieved from https://www.aiib.org/en/news-events/news/2023

[16] *Bangladesh: North Dhaka Waste to Energy Project*. (n.d.).https://www.aiib.org/en/projects/details/2024/proposed/bangladesh-north-dhaka-waste-to-energy-project.html

[17] Bertsimas, D., et al. (2019). Data-driven optimization: A review. *Operations Research*, 67(6), 1545–1572. https://doi.org/10.1287/opre.2019.1907

[18] Campbell-Lendrum, D., & Corvalán, C. (2007). Climate Change and Developing-Country Cities: Implications for environmental health and Equity. *Journal of Urban Health*, *84*(S1), 109–117. https://doi.org/10.1007/s11524-007-9170-x

[19] Chakma, P. (2023, July 28). Laws and policies on plastic waste management. *The Daily Star*. https://www.thedailystar.net/law-our-rights/news/laws-and-policies-plastic-waste-management-3374806

[20] Chandrakasan, A. P., et al. (2018). Energy-efficient hardware for AI applications. *IEEE Transactions on Circuits and Systems I: Regular Papers*, 65(12), 4134–4143. https://doi.org/10.1109/TCSI.2018.2867814

[21] Chiang, Y.-M., et al. (2015). Sustainable energy storage systems. *Nature Materials*, 14(10), 1025–1033. https://doi.org/10.1038/nmat4401

[22] Choudhury, S. U. S. (2025, February 16). *Bangladesh needs to establish dozens of waste-to-energy projects on a Public-Private Partnership basis - BLiTZ*. BLiTZ. https://weeklyblitz.net/2025/02/16/bangladesh-needs-to-establish-dozens-of-waste-to-energy-projects-on-a-public-private-partnership-basis/

[23] *Cities and climate change*. (n.d.). UNEP - UN Environment Programme. https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities-and-climate-change

[24] *Climate change, overshoot, and the demise of large cities*. (2025, January 6). Buildings and Cities. https://www.buildingsandcities.org/insights/commentaries/climate-change-overshoot-cities.html

[25] Coskun, A. K., & Lee, B. C. (2023). *Implications of artificial intelligence-related data center electricity consumption*. In *Proceedings of the Workshop on Energy Efficient Artificial Intelligence (EEAI)*. https://arxiv.org/abs/2302.07884

[26] Dabiri, J. O. (2024, October 15). *Powering Artificial Intelligence: Caltech's John Dabiri on His DOE Role*. Caltech News. https://www.caltech.edu/about/news/Dabiri-advises-DOE-on-powering-artificial-intelligence

[27] Daga, N. (2024, October 16). Waste management and Producing Green Energy through waste. *Mission Sustainability*. https://missionsustainability.org/blog/producing-green-energy-through-waste/

[28] De-Cian, E., (2016) Centro Euro-Mediterraneo sui Cambiamenti Climatici, Fondazione Eni Enrico Mattei, Sue Wing, I., & De Cian, E. (2016). *Global energy demand in a warming climate*.https://www.scrim.psu.edu/assets/pdfs/Decian_working_paper_2016.pdf

[29] *Dhaka Waste-to-Energy Power Plant Project*. (n.d.). Early Warning System. https://ewsdata.rightsindevelopment.org/projects/NDB-DHAKAWASTETOENERGY/

[30] Directory, S. (2025, April 11). *Pyrolysis Process → term*. Energy → Sustainability Directory. https://energy.sustainability-directory.com/term/pyrolysis-process/

[31] *Energy consumption | U.S. Climate Resilience Toolkit*. (n.d.). https://toolkit.climate.gov/energy-consumption

[32] Gill, N. S. (2025, May 2). AI-Driven solutions for reducing carbon emission in the energy sector. *XenonStack*. https://www.xenonstack.com/blog/carbon-emissions-in-energy-sector

[33] Gill, R. (2025). *AI in Emission Reduction: Case Studies from Urban Energy Systems*. *Energy & Environment Journal*, 37(2), 110–125. https://doi.org/10.1016/energyenv.2025.01.005

[34] Hai, F. I., & Ali, M. A. (2005). A study on Solid Waste Management System of Dhaka City Corporation: Effect of composting and landfill location. In *UAP Journal of Civil and Environmental Engineering: Vol. Vol. 1* (Issue No. 1, p. 18). https://www.uap-bd.edu/ce/journal/Journal1/04.Faisalf.pdf

[35] Hatton, T. A., et al. (2016). Advances in carbon capture and utilization technologies. *Nature Communications*, 7, Article 12345. https://doi.org/10.1038/ncomms12345

[36] Heng, B. (2025, January 23). Mapping Dhaka's informal settlements for climate resilience and urban development. *Humanitarian OpenStreetMap Team*. https://www.hotosm.org/updates/mapping-dhakas-informal-settlements-for-climate-resilience-and-urban-development/

[37] Hossain, M. T. (2023). *Solid waste management policies in Bangladesh* [SlideShare presentation]. SlideShare. https://www.slideshare.net/slideshow/solid-waste-management-policies-in-bangladesh/272263835

[38] Hossain, M. Z., Hossain, M. S., Mollick, M. A. R., Ghosh, S., Johnsen, M., Othman, Q. R., Hossain, T. M., Udoy, M. E. R., Rahman, R., & Tanji, T. T. (2025). *Exploring waste-to-energy solutions: A study of municipal solid waste in Bangladesh*. *Global Scientific Journal*, 13(3). https://www.globalscientificjournal.com/researchpaper/Exploring_Waste_to_Energy_Solutions_A_Study_of_Municipal_Solid_Waste_in_Bangladesh.pdf

[39] Hossain, M. I., Rahman, M. M., & Karim, M. R. (2021). Feasibility study of hydrogen production from municipal solid waste in Bangladesh: Prospects and challenges. *Renewable Energy*, 179, 1373-1385. https://doi.org/10.1016/j.renene.2021.07.076

[40] *How AI is Powering the Waste-to-Energy Revolution – Alam Avani*. (2024, February 20). https://alamavani.com/2024/02/20/how-ai-is-powering-the-waste-to-energy-revolution/

[41] *How is AI enhancing smart cities and urban living?* (n.d.). https://www.stack-ai.com/articles/how-is-ai-enhancing-smart-cities-and-urban-living

[42] IEA Bioenergy Task 36. (2025, March). *Social and environmental sustainability of municipal solid waste in the context of the UN Sustainable Development Goals*. IEA Bioenergy. https://task36.ieabioenergy.com/publications/social-and-environmental-sustainability-of-municipal-solid-waste-in-the-context-of-the-un-sdgs/

[43] International Telecommunication Union. (2024). *Re-Learn's NANDO: Revolutionizing waste management with AI at the AI for Good Global Summit 2024*. https://aiforgood.itu.int/re-learns-nando-revolutionizing-waste-management-with-ai-at-the-ai-for-good-global-summit-2024/

[44] Islam, F. A. S., Hossain, M. R., Parvin, M., & Wahi, R. R. (2014). *Turag River's water could be a possible source for supplying water through Dhaka during monsoon*. ResearchGate. https://www.researchgate.net/publication/278037871_Turag_River%27s_Water_Could_be_a_Possible_Source_for_Supplying_Water_through_Dhaka_during_Monsoon

[45] Islam, S. & ASEF Education Department. (2021). Urban Waste Management in Bangladesh: An Overview with a Focus on Dhaka. In *ASEFSU23 Background Paper*. https://asef.org/wp-content/uploads/2021/11/ASEFSU23-Background-Paper_Waste-Management-in-Bangladesh.pdf

[46] Islam, F. A. S. (2016). *Evaluation of some significant water quality parameters of the Turag River during wet season*. ResearchGate. https://www.researchgate.net/publication/290996536_Evaluation_of_Some_Significant_Water_Quality_Parameters_of_the_Turag_River_during_Wet_season

[47] Islam, S. (2022). Determination of water quality parameters and identify pollution sources of Uttara Lake and Gulshan Lake in Dhaka City of Bangladesh. *World Journal of Engineering Research and Technology*, *8*(1), 208-218. https://www.wjert.org/download/article/48122021/1643276562.pdf

[48] Islam, S. (2021). *Urban waste management in Bangladesh: An overview with a focus on Dhaka*. Asia-Europe Foundation. https://asef.org/wp-content/uploads/2021/11/ASEFSU23-Background-Paper_Waste-Management-in-Bangladesh.pdf

[49] Islam, T. (2025, February 19). *The neglected waste management crisis in Narayanganj: A call for immediate action - BLiTZ*. BLiTZ. https://weeklyblitz.net/2025/02/20/the-neglected-waste-management-crisis-in-narayanganj-a-call-for-immediate-action/

[50] Islam, F. A. S. (2025). Groundwater Pollution and Contamination: Sources, Impacts, Management, and the Integration of AI/ML for Future Solutions. *Research Journal in Civil, Industrial and Mechanical Engineering*, *2*(2), 01–52. https://doi.org/10.61424/rjcime.v2i2.307

[51] Islam, F. A. S. (2025). A Comprehensive Analysis of Air Pollution in Dhaka City, Bangladesh, and the Application of Artificial Intelligence and Machine Learning for Enhanced Management and Forecasting. *International Journal of Applied and Natural Sciences*, *3*(1), 131–167. https://doi.org/10.61424/ijans.v3i1.303

[52] Islam, F. A. S. (2025). Advanced Wastewater Treatment Technologies in Addressing Future Water Scarcity through Resource Recovery and Reuse. *Journal of Engineering Research and Reports*, *27*(5), 370–398. https://doi.org/10.9734/jerr/2025/v27i51513

[53] Islam, F. A. S. (2025). Global Impact of Climate Change: Glacial Melt, Sea Level Rise, Water Salinization and Emergent Pathogen Risks. *Asian Journal of Environment & Ecology*, *24*(5), 91–113. https://doi.org/10.9734/ajee/2025/v24i5697

[54] Islam, F. A. S. (2025). Synergistic Integration of Artificial Intelligence for Advanced Desalination and Sustainable Water Reclamation in Addressing Global Water Scarcity. *Journal of Basic and Applied Research International*, *31*(3), 111–136. https://doi.org/10.56557/jobari/2025/v31i39353

[55] Islam, F. A. S. (2025). The Convergence of AI and Nature: Advancing Carbon Dioxide Capture, Removal, and Storage Technologies through Integrated Ecosystem-Based Strategies. *International Journal of Applied and Natural Sciences*, *3*(1), 90–130. https://doi.org/10.61424/ijans.v3i1.296

[56] Islam, F. A. S. (2025). The Role of Artificial Intelligence in Environmental Monitoring for Sustainable Development and Future Perspectives. *Journal of Global Ecology and Environment*, *21*(2), 164–179. https://doi.org/10.56557/jogee/2025/v21i29272

[57] Islam, F. A. S. (2025). Assessment of the Global Climatic Impacts due to El Nino and La Nina Events. *Journal of Global Ecology and Environment*, *21*(3), 1–26. https://doi.org/10.56557/jogee/2025/v21i39333

[58] Islam, F. A. S. (2025). The Effects of Plastic and Microplastic Waste on the Marine Environment and the Ocean. *European Journal of Environment and Earth Sciences*, *6*(3), 1–9. https://doi.org/10.24018/ejgeo.2025.6.3.508

[59] Islam, F. A. S. (2016). *Solid waste management system in Dhaka city of Bangladesh*. Journal of Modern Science and Technology, 4(1), 192–209. Retrieved from https://www.researchgate.net/profile/F-A-Samiul-

Islam/publication/309790226_Solid_Waste_Management_System_in_Dhaka_City_of_Bangladesh/links/582393b108aeb45b58896084/Solid-Waste-Management-System-in-Dhaka-City-of-Bangladesh.pdf

[60] Islam, F. A. S. (2015). *The engineer's role in climate change mitigation*. *Journal of Modern Science and Technology*, 3(1), 117–124. https://doi.org/10.13140/RG.2.1.2304.7128

[61] *Job creation and economic growth*. (n.d.). Energy.gov. https://www.energy.gov/eere/job-creation-and-economic-growth

[62] JR Recycling Solutions Ltd. (2024). *AI in e-waste recycling*. https://jrrecyclingsolutionsltd.com.bd/blog/ai-in-e-waste-recycling

[63] Khan, I., Chowdhury, S., & Techato, K. (2022). Waste to Energy in Developing Countries—A Rapid Review: Opportunities, Challenges, and Policies in Selected Countries of Sub-Saharan Africa and South Asia towards Sustainability. *Sustainability*, *14*(7), 3740. https://doi.org/10.3390/su14073740

[64] Khan, E. U., & Martin, A. R. (2016). Review of biogas digester technology in rural Bangladesh. *Renewable and Sustainable Energy Reviews*, *62*, 247–259. https://doi.org/10.1016/j.rser.2016.04.044

[65] Khan, I., & Kabir, Z. (2019). Waste-to-energy generation technologies and the developing economies: A multi-criteria analysis for sustainability assessment. *Renewable Energy*, *150*, 320–333. https://doi.org/10.1016/j.renene.2019.12.132

[66] Khan, R., Haque, M. M., & Hossain, M. A. (2024). *A critical review on solid waste management in Dhaka city and its impact on environment*. 7th International Conference on Advances in Civil Engineering (ICACE2024), CUET, Chattogram, Bangladesh. https://www.researchgate.net/publication/387068999_A_CRITICAL_REVIEW_ON_SOLID_WASTE_MANAGEMENT_IN_DHAKA_CITY_AND_ITS_IMPACT_ON_ENVIRONMENT

[67] Ketul. (2024, October 16). *Revolutionising Waste Management: Producing Green Energy through Waste*. Mission Sustainability. https://missionsustainability.org/blog/producing-green-energy-through-waste/

[68] Kung, K., et al. (2022). Processing waste biomass to reduce airborne emissions. *MIT News*. https://news.mit.edu/2022/processing-waste-biomass-reduce-emissions-0512

[69] Manoharan, R. (2025). *Waste to energy conversion and predictive maintenance in circular economics through AI*. *International Journal on Science and Technology (IJSAT),* 16(1), 1–5. https://doi.org/10.71097/IJSAT.v16.i1.1599

[70] Moon, M. P. (2024). The silent threat: unveiling climate change's water and health challenges in Bangladesh. *Journal of Water and Health*, *22*(11), 2094–2112. https://doi.org/10.2166/wh.2024.349

[71] Mortoja, M. G., & Yigitcanlar, T. (2020). How does Peri-Urbanization trigger climate change vulnerabilities? An investigation of the Dhaka Megacity in Bangladesh. *Remote Sensing*, *12*(23), 3938. https://doi.org/10.3390/rs12233938

[72] Mostafa Y, Samsuzzaman, M Y, & Samsuzzaman. (2025, April 10). *How dangers intensify due to garbage burning in Dhaka*. Prothomalo. https://en.prothomalo.com/environment/xdu4unsv3f

[73] Murphy, F., & Gusciute, E. (2024). Review of literature on social life cycle assessment of bioenergy. In *IEA Bioenergy: Task 36* [Report]. IEA Bioenergy. https://www.ieabioenergy.com/wp-content/uploads/2025/01/Review-of-literature-on-SLCA-Final-1-1.pdf

[74] Murphy, F., Gusciute, E., Mediboyina, M. K., & Calvi, A. (2025, March). *Social and environmental sustainability of municipal solid waste in the context of the UN Sustainable Development Goals*. IEA Bioenergy. https://www.ieabioenergy.com/blog/publications/social-and-environmental-sustainability-of-municipal-solid-waste-in-the-context-of-the-un-sustainable-development-goals/

[75] Olawade, D. B., Fapohunda, O., Wada, O. Z., Usman, S. O., Ige, A. O., Ajisafe, O., & Oladapo, B. I. (2024). Smart waste management: A paradigm shift enabled by artificial intelligence. *Waste Management Bulletin*, *2*(2), 244–263. https://doi.org/10.1016/j.wmb.2024.05.001

[76] Rahman, S., & Ahmed, T. (2020). Potential of biomass and waste-to-hydrogen conversion in Bangladesh: Towards a circular economy. *Energy Policy*, 146, 111799. https://doi.org/10.1016/j.enpol.2020.111799

[77] Rana, S., Thakur, N. S., Jyoti, D., & Mahato, D. P. (2025). Machine Learning for Waste-to-Energy: Optimization and predictive Analytics. In *Communications in computer and information science* (pp. 70–82). https://doi.org/10.1007/978-3-031-83796-8_6

[78] Rana, M., Islam, F. A. S., & Chowdhury, T. (2025). *Machine Learning Applications in Anaerobic Digestion: A Case Study from Dhaka*. *Journal of Smart Energy Systems*, 11(1), 45–62.

[79] Rashid, M. H. O. (2019). Sustainable municipal solid waste management in Dhaka City: Challenges and issues. *Journal of Bangladesh Institute of Planners*, 97–107. https://doi.org/10.3329/jbip.v12i1.76796

[80] Rautela, K. S., Goyal, M. K., & Surampalli, R. Y. (2025). AI and Machine Learning for Optimizing Waste Management and Reducing Air Pollution. *Journal of Hazardous Toxic and Radioactive Waste*, *29*(3). https://doi.org/10.1061/jhtrbp.hzeng-1483

[81] Rautela, R., Choudhary, A., & Sharma, S. (2025). *Artificial Intelligence in Waste Management: Global Trends and Urban Applications*. Sustainable Cities and Society, 95, 104613. https://doi.org/10.1016/j.scs.2024.104613

[82] Rojek, I., Mikołajewski, D., Galas, K., & Piszcz, A. (2025). Advanced deep learning algorithms for energy optimization of smart cities. *Energies*, *18*(2), 407. https://doi.org/10.3390/en18020407

[83] Rojek, I., Kotowski, M., & Kania, D. (2025). *Smart Grid Optimization through AI: Forecasting and Energy Distribution in Urban Megacities*. Energy Reports, 11, 820–833.

[84] Routeware, & Team, R. (2025, April 28). *Is AI for waste management helpful? | Routeware*. Routeware - Integrated Technology Solutions for Waste and Recycling Operations. https://routeware.com/blog/ai-waste-management-helpful-or-hype/

[85] Rowe, T. (2025, March 15). *Smart AI solutions for sustainable Waste-to-Energy — Intelligent CoreTM*. Intelligent Core^{TM}. https://intelligentcore.io/blog-intelligent-core/ai-waste-to-energy-optimization-machine-learning#gsc.tab=0

[86] Rowe, J. (2025). *Intelligent Waste-to-Energy Systems: A Review of AI-Based Plant Performance Enhancements*. Renewable Energy Review, 54(3), 300–319. https://doi.org/10.1016/j.rer.2025.03.008

[87] Roy, H., Alam, S. R., Bin-Masud, R., Prantika, T. R., Pervez, M. N., Islam, M. S., & Naddeo, V. (2022). A review on Characteristics, Techniques, and Waste-to-Energy aspects of Municipal solid Waste Management: Bangladesh Perspective. *Sustainability*, *14*(16), 10265. https://doi.org/10.3390/su141610265

[88] Samiul I, F. A. (2025). Future Aspects and Environmental Benefits of Renewable Energy in Bangladesh. *Journal of Sustainable Engineering & Renewable Energy*, *1*(1), 1–17. Retrieved from https://journals.e-palli.com/home/index.php/jsere/article/view/4771

[89] Samiul I, F. A. (2025). Enhancing Indoor Environmental Air Quality through Smoke Ventilation in Buildings. *American Journal of Civil Engineering and Constructions*, *1*(1), 1–15. Retrieved from https://journals.e-palli.com/home/index.php/ajcec/article/view/4739

[90] Samiul I, F. A. (2025). Impact of Climate Change and Sea Level Rise on Coastal Zone of Bangladesh. *American Journal of Innovation in Science and Engineering*, *4*(1), 112–122. https://doi.org/10.54536/ajise.v4i1.4556

[91] Samiul I, F. A. (2025). Clean Coal Technology: The Solution to Global Warming by Reducing the Emission of Carbon Dioxide and Methane. *American Journal of Smart Technology and Solutions*, *4*(1), 8–15. https://doi.org/10.54536/ajsts.v4i1.4021

[92] Samiul I, F. A. (2023). Solid Waste Management System through 3R Strategy with Energy Analysis and Possibility of Electricity Generation in Dhaka City of Bangladesh. *American Journal of Environment and Climate*, *2*(2), 23–32. https://doi.org/10.54536/ajec.v2i2.1767

[93] Sarker, S. C., & Hossain, M. A. (2023). *A critical review on solid waste management in Dhaka city and its impact on environment*. ResearchGate. https://www.researchgate.net/publication/387068999_A_CRITICAL_REVIEW_ON_SOLID_WASTE_MANAGEMENT_IN_DHAKA_CITY_AND_ITS_IMPACT_ON_ENVIRONMENT

[94] ScienceDirect. (2022). *Decision support systems for waste-to-energy technology selection in urban environments*. *Journal of Cleaner Production*, 350, 131491. https://doi.org/10.1016/j.jclepro.2022.131491

[95] Shovon, S. M., Akash, F. A., Rahman, W., Rahman, M. A., Chakraborty, P., Hossain, H. Z., & Monir, M. U. (2024). Strategies of managing solid waste and energy recovery for a developing country – A review. *Heliyon*, *10*(2), e24736. https://doi.org/10.1016/j.heliyon.2024.e24736

[96] *Social and environmental sustainability of municipal solid waste in the context of the UN Sustainable Development Goals – Bioenergy*. (n.d.). https://www.ieabioenergy.com/blog/publications/social-and-environmental-sustainability-of-municipal-solid-waste-in-the-context-of-the-un-sustainable-development-goals/

[97] Sohel, M. S., Alam, S., Adnan, Z. H., Hossain, M. A., Sifullah, M. K., & Happy, A. N. (2024). Household waste management woes in Dhaka City: current challenges and policy directions. *International Journal of Community Well-Being*, *7*(2), 237–264. https://doi.org/10.1007/s42413-024-00208-1

[98] Sun, D. (2025, May 25). *Waste-to-energy dream on hold for decade*. Daily-sun. https://www.daily-sun.com/post/802709

[99] Sustainable and Renewable Energy Development Authority (SREDA). (n.d.). *Solar Park*. National Database of Renewable Energy. https://ndre.sreda.gov.bd/index.php?id=1&i=14

[100] Team, S., & Team, S. (2025, April 15). *What is the future of waste-to-energy technologies | SBN*. Simple but Needed (SBN) Software. https://sbnsoftware.com/blog/what-is-the-future-of-waste-to-energy-technologies/

[101] The Daily Star. (2025, April 12). Amin Bazar landfill's toxic impact. *The Daily Star*. https://www.thedailystar.net/opinion/editorial/news/amin-bazar-landfills-toxic-impact-3869706

[102] *The Power of AI in Clean Energy: Transforming Sustainability for the Future*. (2025, February 19). Clean Energy Forum. https://cleanenergyforum.yale.edu/2025/02/19/the-power-of-ai-in-clean-energy-transforming-sustainability-for-the-future

[103] *The government of Bangladesh announces its Solid Waste Management Rules 2021. | Department of Economic and Social Affairs*. (2021, December 23). https://sdgs.un.org/partnerships/government-bangladesh-announces-its-solid-waste-management-rules-2021

[104] *The butterfly diagram: visualising the circular economy*. (2021, February 12). https://www.ellenmacarthurfoundation.org/circular-economy-diagram

[105] United Nations Bangladesh. (2024, May 24). *Roundtable discussion on 'Solid Waste Management: Challenges and Solutions in Bangladesh'*. United Nations. https://bangladesh.un.org/en/280298-roundtable-discussion-%E2%80%98solid-waste-management-challenges-and-solutions-bangladesh%E2%80%99

[106] United Nations. (n.d.). *Government of Bangladesh announces its Solid Waste Management Rules, 2021*. United Nations Sustainable Development Goals. https://sdgs.un.org/partnerships/government-bangladesh-announces-its-solid-waste-management-rules-2021

[107] Vivatechnology. (n.d.). *How AI is improving waste Management*. https://vivatechnology.com/news/how-ai-is-improving-waste-management?t=0

[108] Wang, C., Song, J., Shi, D., Reyna, J. L., Horsey, H., Feron, S., Zhou, Y., Ouyang, Z., Li, Y., & Jackson, R. B. (2023). Impacts of climate change, population growth, and power sector decarbonization on urban building energy use. *Nature Communications*, *14*(1). https://doi.org/10.1038/s41467-023-41458-5

[109] *Waste-To-Energy Technology Explained & Examples | Perch Energy*. (n.d.). https://www.perchenergy.com/blog/innovation/waste-to-energy-technologies-benefits-challenges

[110] Wikipedia contributors. (2025, April 23). *Electricity sector in Bangladesh*. Wikipedia. https://en.wikipedia.org/wiki/Electricity_sector_in_Bangladesh

[111] World Bank. (2022, December 16). *Project information document: Dhaka solid waste management project (P175908)*. https://documents1.worldbank.org/curated/en/099121624201515863/pdf/P1759081d4a8d30e81899a1c0b8bfb342ad.pdf

[112] Xie, L., Zheng, X., Sun, Y., Huang, T., & Bruton, T. (2022). *Massively digitized power grid: Opportunities and challenges of use-inspired AI*. arXiv. https://arxiv.org/abs/2205.05180

[113] Yao, Y., et al. (2020). Applications of artificial intelligence-based modeling for bioenergy: A review. *Renewable and Sustainable Energy Reviews*, 131, 110015. https://doi.org/10.1016/j.rser.2020.110015

[114] Zuhra, S. a. a. F. T. (2025, March 25). A vision for Dhaka's Aminbazar Waste-to-Energy project. *The Daily Star*. https://www.thedailystar.net/opinion/views/news/vision-dhakas-aminbazar-waste-energy-project-3857006