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Optimization of a proposed biomass generator: Harnessing citizen waste with electric vehicle charging infrastructure

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ABSTRACT

Global municipal solid waste production is rising, causing significant environmental, health, and economic issues. Developed countries have advanced recycling technologies, but cities like Dhaka, Bangladesh—among the most densely populated-struggle with inadequate waste management. This feasibility study aims to improve environmental protection and create new energy sources by proposing a waste management system across Dhaka, focusing on waste valorization for bioenergy with optimized efficiency and minimal impact. The study includes design and optimization of a biomass-based power plant to meet the energy needs of EV charging stations and the national grid, evaluating its economic performance through discounted cash flow and payback period analyses. The paper explores the integration of an EV charging station powered by biogas, addressing the growing need for EV infrastructure in Dhaka. By evaluating biomass generators as a greener alternative to fossil fuels, the study analyzes the technical, economic, and environmental feasibility, including CO2 emissions, using HOMER Pro.

1. Introduction

Municipal solid waste (MSW) management is a significant global challenge. Municipal solid wastes are composed of organic and inorganic substances and their qualitative and quantitative composition varies from country to country. The World Bank projects that approximately 1.3 billion tons of MSW are collected worldwide annually, with an anticipated increase to 2.2 billion tons per year by 2025 (Yusuf and Kusumah, 2022). This escalating volume is attributed to population growth and the expansion of socioeconomic activities. These figures underscore the pressing need to tackle the escalating challenge of municipal waste management.

Solid waste management has emerged as a critical concern in both urban and rural areas in Bangladesh. Managing urban solid waste presents a formidable challenge in developing nations, particularly in large urban centers, such as Dhaka. The complexities of solid waste management underscore the urgent need for comprehensive strategies to address this pressing issue and to ensure the sustainability of urban environments in Bangladesh. However, waste collection services remain insufficient, leaving large, underserved areas.

Almost 40–60 % of the waste is collected and dumped in landfills, but uncollected waste is dumped mostly on the roadside. Despite the significant daily production of municipal solid waste (MSW), over 80 % of the waste stream consists of organic matter, comprising diverse substances, including food waste, paper, cloth, agricultural remnants, construction debris, metals, hospital waste, and appliances and 50–70 % moisture; approximately 50 % of the waste undergoes proper collection and landfill disposal by the two region of Dhaka City Corporations (DCC), Dhaka North City Corporation (DNCC), and Dhaka South City Corporation (DSCC) (Prodhan and Kaeserb, 2019). Due to cultural customs and dietary preferences, a considerable amount of waste consists of food and vegetable scraps. The inadequacy of waste management practices results in a substantial volume of uncollected waste, thereby fostering environmental hazards within the city.

Abbreviations: BPDB, Bangladesh Power Development Board; DCC, Dhaka City Corporations; DNCC, Dhaka North City Corporation; DSCC, Dhaka South City Corporation; GIZ, Gesellschaft für Internationale Zusammenarbeit; MSW, Municipal Solid Waste; SREDA, Sustainable and Renewable Energy Development Authority; WTE, waste-to-energy.

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Each City Corporation operates a central waste disposal Centre, with DSCC located at Matuail, Demra, Dhaka, and DNCC, spanning 50 acres at Amin Bazar, Savar, Dhaka. Waste generation in Dhaka varies between the Old Town and New Town areas, totaling approximately 1.65 million metric tons annually. Per capita waste generation ranges from 0.29 to 0.60 kg, depending on income levels. Currently, Dhaka produces 4600–5110 tons of waste per day (Hasan and Iqbal, 2016). Waste collection and disposal fall under the jurisdiction of the DNCC and DSCC.

Biomass energy has rapidly become a vital part of global renewable energy and accounts for an ever-growing share of the electric capacity worldwide. Biomass continues to be extensively used in numerous developing nations worldwide. There is increasing interest in using solid wastes as renewable and eco-friendly energy sources. These wastes are valuable raw materials for producing bioenergy, providing avenues to reduce waste volume, meet significant energy needs, and reduce dependence on natural resources (Aboudaoud et al., 2021). This approach offers a promising alternative to traditional crude oil, especially given the global oil crises of recent decades, which have spurred countries to seek new strategies for substituting petroleum-derived fuels with biofuels and embracing principles of green engineering (Aboudaoud et al., 2021). As an agricultural country, Bangladesh possesses abundant resources, such as cattle dung, agricultural residue, poultry droppings, water hyacinth, and rice husk, all of which are utilized for power generation. Private organizations have already begun harnessing these biomass sources to produce electricity to mitigate the country's energy crisis.

A feasibility study by GIZ, the German Development Agency, and SREDA in Bangladesh examined MSW electricity generation in Keraniganj, Dhaka, recommending dry fermentation technology for a 4–5 MW waste-to-energy project with a goal of 1 MW combined heat and power. The study highlights the need to consider per capita MSW generation, estimated at 0.5 kg in Bangladesh, to understand electricity generation potentials (Karmaker et al., 2020).

Previous research has explored various renewable energy solutions, including a hybrid solar-wind-biogas system to evaluate resource potential (Saifullah et al., 2023), and optimized MSW processing for high-energy fuel (Aboudaoud et al., 2021; Wickramasinghe et al., 2019). Other studies have analyzed the economic and environmental impacts of small-scale biowaste-to-energy technologies, including biomass gasification and the use of waste heat for cooling with absorption chillers (Rivas et al., 2020; Stamenić and Gajić, 2021). Research on using hydrogen for incinerating MSW has shown that while it performs well with low-moisture waste, high moisture content hampers efficiency, indicating a need for further optimization (Butt et al., 2022). Additionally, various studies have evaluated waste-to-energy technologies—thermal, biological, biorefinery, and landfill gas utilization—to convert urban solid waste into renewable energy and address global waste management challenges (Yusuf and Kusumah, 2022). Abrar and Hasan (2019) explored using MSW for power generation in Chittagong City as a sustainable solution to energy needs, addressing issues of rising demand and environmental concerns.

However, there appears to be a gap in research specifically on the feasibility of using MSW residues in Bangladesh for electricity generation through a biomass-based power plant with an integrated EV charging station. Thus, the current study is a novel contribution, aiming to fill this research gap and enhance knowledge in this area.

The purpose of this paper is a feasibility study of the potential of utilizing MSW residues from Dhaka city as a possible option for the provision of power in the national grid and electric vehicle (EV) charging stations. The primary objective of the study is to present a preliminary design of a biomass-based power plant system that is capable of satisfying the energy needs of the EV charging station and supplying additional power to the national grid, and to compare its economic performance in respect of existing system, by making use of discounted cash flow and payback period. Additionally, growing concerns about global warming and environmental pollution are driving the shift from fossil fuel-powered generators to greener alternatives. In this context, biomass generators present a compelling option due to their low carbon impact and reduced investment and development costs. The paper examines the technical, economic, and environmental feasibility, of both the integration and sizing of a biomass-based power plant, for electrification in the national grid as well as the electric vehicle charging station. In addition, the impact of related CO2 emissions is also analyzed, and compared to traditional solutions. The study is essentially performed employing the simulation tool referred to as HOMER Pro.

The rest of the article is organized along these lines: Section 2 provides a full description of the process of electricity generation from solid waste. Section 3 gives the technical details of biomass production and Section 4 provides the mathematical model of the proposed system. System design and Simulation results are discussed in Section 5 and Section 6, including the optimal sizing of the system and the cost analysis. Finally, conclusions are drawn in Section 7.

2. Potential electricity generation from solid waste

MSW has untapped energy potential, which is often overlooked. With a calorific value suitable for heating and electricity production, waste-to-energy (WTE) processes offer a solution for MSW disposal while enhancing environmental quality and urban lifestyles. Dhaka City Corporation's MSW, comprising mostly food or vegetable waste with high moisture content, possesses a calorific value of 7.96 MJ/kg, sufficient for electricity generation (Omer, 2011; Wasim and Nine, 2017). This presents an opportunity for alternative electricity sources in the Dhaka North and South City Corporation, as illustrated in the waste-to-energy generation flow chart (Fig. 1).

The biomass gasification system (BGS) aims to convert agriculture and forestry into combustible gas. This gas serves as fuel for both thermal and electrical power applications. Biomass gasification overcomes biomass limitations, such as low flammability and diverse composition, requiring minimal land and environmental friendliness. BGS is a notable method for sustainable energy production because of its ability to utilize biomass efficiently (Fig. 1).

Initially, the energy content of the MSW was assessed using a modified version of Dulong's formula. Subsequently, the potential electricity generated from this solid waste energy was computed. Modified Dulong Equation (Wasim and Nine, 2017):

$$Heat\ Energy, Q = (337C + 1428(H - O/8) + 9S)kJ/kg, \tag{1}$$

where, C, Percentage of Carbon; H, Percentage of Hydrogen; O, Percentage of Oxygen; S, Percentage of Sulfur.

$$Stream\ Energy\ Available,\ Es = 0.7xQ \tag{2}$$

$$Electric\ Power\ Generation,\ Ep = Es/11395 \tag{3}$$

$$Station\ Service\ Allowance,\ SA = 0.06xEp \tag{4}$$

$$Uncounted\ Heat\ Loss,\ UH = 0.05xEp \tag{5}$$

Therefore, Net Electric Power Generation,

$$ENP = Ep - SA - UH \tag{6}$$

The total municipal solid waste generated in Dhaka City is approximately 6000 tons/day. As a result, a net electric power of 34.5 MWh/day can be produced from this amount of solid waste. This could support our national power grid as well as environmental conservation.

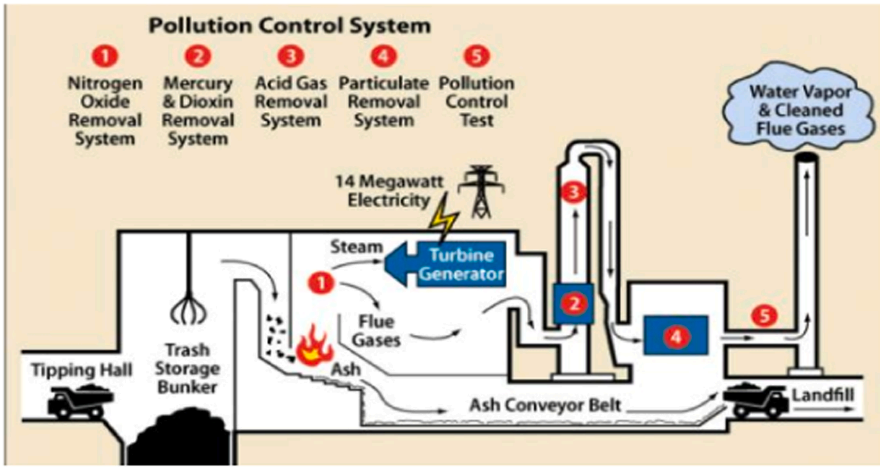

Fig. 1. Solid waste to Energy generation process (Karmaker et al., 2020).

3. Technology details

3.1. Biogas composition

Biomass, derived from plant and animal wastes, is a renewable organic material. It can undergo various processes for conversion into renewable liquid and gaseous fuels, primarily consisting of a mixture of gases. Methane (CH_4) and carbon dioxide (CO_2) are the main components in anaerobic bacterial decomposition. Biogas, containing methane and carbon dioxide along with other gases, has significant potential in Bangladesh, where biodegradable resources such as animal waste, food substrates, wood, paper, and municipal solid waste are abundant. Table 1 displays the chemical composition of the biogas.

Municipal solid waste, primarily composed of food and vegetable waste constituting 65 % and 80 % organic content, respectively, has significant potential for biogas generation. By efficiently utilizing the organic content, particularly food waste, substantial biogas production can be achieved, offering a solution to escalating energy demands. Commonly used residues for biogas production include animal manure, agricultural residues, organic fractions of municipal waste, and residues from energy crops. These substrates vary based on origin, organic content, methane yield, and dry matter content, significantly affecting the biogas yield. Lower carbon-to-nitrogen ratios typically result in higher biogas yields, indicating the importance of substrate selection for optimal biogas production (Thilak et al., 2023).

Different biomass types exhibit varying impacts on biogas yield. For instance, utilizing straw yields around 0.15 m^3/kg volatile solids (VS) of biogas, whereas concentrated whey leads to a remarkable 500 % increase, resulting in a 0.9 m^3/kg VS (Table 2). The carbon-to-nitrogen (C:N) ratio also affects biogas production. Lower C:N ratios (3–20) typically yield between 0.25 and 0.78 m^3/kg VS, whereas higher ratios (above 20, up to 150) result in a maximum yield of 0.56 m^3/kg VS, approximately 30 % lower than lower ratios (da Silva et al., 2017).

Table 1
Percentage of different types of gases composition in biogas (da Silva et al., 2017).

Gas	Percentage (%)
Methane (CH_4)	55–65 %
Carbon dioxide (CO_2)	35–45 %
Hydrogen (H_2)	0–1 %
Hydrogen sulfide (H_2S)	0–1 %
Ammonia (NH_3)	0–1 %
Nitrogen (N_2)	0–3 %
Oxygen (O_2)	0–1 %
Hydrogen (H_2)	0–1 %

Table 2
Substrates commonly utilized for biogas production, its composition, and average biogas yield (da Silva et al., 2017).

Biomass type	Organic content	C:N ratio	Dm[a] (%)	VS[b] (% of DM)	Biogas (yield m^3/kg VS)
Slurry (Cattle)	Carbohydrat, proteins, lipids	6–20	5–12	80	0.20–0.30
Slurry (Poultry)		3–10	10–30	80	0.35–0.60
Stomach/ intestine content		3–5	15	80	0.40–0.68
Whey	75–80 % lactose, 20–25 % proteins	NR	8–12	90	0.35–0.80
Concentrated whey			20–25	90	0.80–0.90
Fermented slops	Carbohydrates	4–10	1–5	80–95	0.35–0.78
Straw		80–100	70–90	80–90	0.15–0.35
Garden wastes		100–150	60–70	90	0.20–0.50
Grass	NR	12–25	20–25	90	0.55
Grass silage		10–25	15–25	90	0.56
Fruit wastes		35	15–20	75	0.25–0.50
Food remains		NR	10	80	0.50–0.60
Fish oil	30–50 % lipids				
Soya oil/ margarine	90 % vegetable oil	NR	NR	NR	NR

[a] Dry matter.
[b] Volatile solids. NR: not reported.

3.2. Proposed area for project

The selection of an appropriate site is the initial challenge in establishing a power plant. Considerations include raw material accessibility, transportation, environmental safety, cost-effectiveness, and proximity to consumption areas, ensuring a minimal impact on residential areas. As the Dhaka City Corporation (DCC) is responsible for collection of waste management in Dhaka and waste from Dhaka is landfilled in Matuail and Amin Bazar, Savar dumping grounds. This study proposes locating a biogas power plant near Dhaka City Corporation, preferably in Savar, because the central waste dumping zone for south city corporation is in Savar and it will help to facilitate the transmission and distribution.

3.3. Electricity generation from biogas

Biogas is a commonly used energy source for both electricity and heat production. Biogas can generate approximately 6 kWh of electricity with a calorific value of approximately 22 MJ/m^3. The efficiency of biogas plants typically ranges between 35 % and 40 % for electricity generation and 45–50 % for heat generation, with the remaining percentage accounting for mechanical losses (da Silva et al., 2017). The combustion of biogas in a burner facilitates heat generation that can be harnessed for nearby applications. Additionally, the heat generated by biogas plants can support various applications, such as heating, wastewater treatment, and landfill operations. Furthermore, the electricity generated can be integrated into the power grid using internal combustion engines fueled with biogas (Liu et al., 2021). The European Union acknowledges the potential of biogas to generate 25 % of all clean energy (Agustina et al., 2018).

3.4. Potential of biogas resources in Bangladesh

Bangladesh possesses significant potential as a biodegradable resource, including animal waste, food substrates, wood, paper, and municipal solid waste, which are primarily utilized as the main sources of biogas.

3.4.1. Animal waste

Animal waste is a significant source of biomass. Approximately 150,000 poultry farms in Bangladesh are catering to chicken and duck farming. Statistics gathered for the fiscal years 2016–2017 indicate the daily waste generation from various livestock, including cattle, buffalo, chicken, and duck, as detailed in Table 3. These waste materials have the potential for power generation.

3.4.2. Agriculture residues

Agricultural residues play a significant role in biomass generation, encompassing materials such as rice husks, crop residues, sugarcane bagasse, forest residues, jute, and vegetables. As a major rice-producing country, Bangladesh primarily generates rice straw and husk residues. Depending on the collection period, crop residues can be categorized as field residues or processed residues, with a recovery rate of 35 % for rice straw and 100 % for rice husk. Sugarcane residue, another potent biomass resource, has a cultivation volume of approximately 4,434,070 metric tons in Bangladesh, with tops, leaves, and bagasse residues being utilized for biomass energy, boasting a recoverable residue rate of 73.42 % for processed bagasse. Additionally, jute serves as another biomass source, with a recoverable rate of 37.12 % (da Silva et al., 2017). These agricultural residues hold promise as biomasses for power generation and heating applications.

3.4.3. Municipal solid waste (MSW)

Waste disposal poses a burgeoning challenge in urban areas, exacerbated by rapid urbanization and industrialization, resulting in approximately 4200 tons of MSW daily in Dhaka City (Karmaker et al., 2020). Improper MSW management can lead to adverse environmental consequences, prompting growing concern. Recognizing the potential for energy generation, stakeholders, including the government, are exploring new solutions.

Bangladesh, with its population of approximately 165 million, ranks among the most densely populated countries globally. Covering an area of 147,570 km^2, it is situated between latitudes 20°34′ and 26°38′ north and longitudes 88°01′ and 92°41′ east (Habib et al., 2021). The country encompasses twelve city corporations, including the Dhaka City Corporation (DCC). The DCC oversees waste management in Dhaka, divided into DCC (North) with 36 wards and DCC (South) with 56 wards. Waste from Dhaka is disposed of in the Matuail and Amin Bazar dumping grounds, with Matuail serving 55 wards and Amin Bazar serving 36 wards (Prodhan and Kaeserb, 2019).

Table 3
Waste generation from livestock (Karmaker et al., 2020).

Waste type	No. of livestock (millions)	Waste generation (tons/day)
Cattle dung	23.93	179,475
Buffalo dung	1.47	14,700
Chicken waste	275.18	27,518
Duck waste	54.01	5401

Dhaka's total population is expanding at an annual rate of 1.4 %, while the urban population is growing even faster at 3.4 % per year. Projections indicate that the population could reach 40 million by 2040, exacerbating the city's waste management challenges (Prodhan and Kaeserb, 2019). Despite their significance, Dhaka's authorities face severe environmental challenges, particularly in solid waste management, due to power shortages, inadequate equipment, and governance issues.

Bangladesh ranks as the third lowest per capita waste-producing country in the region, with a daily MSW generation of approximately 0.5 kg per person (Habib et al., 2021). These estimated waste volumes were subsequently converted into landfill space requirements by dividing them by the compacted specific weight of waste in landfills, which is 500 kg per cubic meter. The demand for landfill space for the disposal of municipal solid waste (MSW) in Dhaka was evaluated by projecting population growth and waste generation from 2007 to 2025, as detailed in Table 4.

Notably, the potential for electrical energy generation surged from 456,900 MWh in 1995 to 1,894,400 MWh in 2025. This growth suggests that electrical energy recovery from urban solid waste in Dhaka could substantially contribute to meeting the city's energy consumption needs (Prodhan and Kaeserb, 2019; Karmaker et al., 2020).

4. Mathematical modeling

4.1. Modeling of biogas generator power

The biogas power potential was be calculated using the values of the biogas production flow rate and estimated heat value. The power produced by the biogas engine–generator ($P_{E,BG}$) can be obtained using the following Equation:

$$P_{E,BG} = \eta_{E,BG} \times Q_{BG}(t) \times LHV_{BG} \tag{7}$$

where, $\eta_{E,BG}$, electrical conversion efficiency (25–40 %); Q_{BG}, biogas flow consumption (m^3/h); LHV_{BG}, low heating value of biogas (kW h/m^3).

The heating value of biogas generated from different organic

Table 4
Population, waste generation and waste volume in Dhaka city (2007–2025) (Prodhan and Kaeserb, 2019).

Year	Projected population (M)	Daily waste generation (tons)	Yearly waste generation (M tons)	Cumulative waste (M tons)	Cumulative landfill waste volume (Mm^3)
2007	13.50	6750	2.5	2.5	4.93
2008	13.87	6934	2.5	5	9.99
2009	14.24	7122	2.6	7.6	15.19
2010	14.63	7316	2.7	10.3	20.53
2011	15.03	7515	2.7	13	26.01
2012	15.44	7719	2.8	15.8	31.65
2013	15.86	7929	2.9	18.7	37.44
2014	16.29	8145	3	21.7	43.38
2015	16.73	8367	3.1	24.7	49.49
2016	17.19	8594	3.1	27.9	55.77
2017	17.66	8828	3.2	31.1	62.21
2018	18.14	9068	3.3	34.4	68.83
2019	18.63	9315	3.4	37.8	75.63
2020	19.14	9568	3.5	41.3	82.61
2021	19.66	9828	3.6	44.9	89.79
2022	20.19	10,096	3.7	48.6	97.16
2023	20.74	10,370	3.8	52.4	104.73
2024	21.30	10,652	3.9	56.3	112.5
2025	21.88	10,952	4.0	60.9	120.49

materials typically falls within the range of 15 to 25 MJ/m^3, with estimation possible by considering the methane percentage in the biogas (da Silva et al., 2017).

To determine the heating value of biogas based on the methane fraction present in organic matter, the following Eq. (8) can be used (da Silva et al., 2017):

$$LHV_{BG} = LHV_{CH4} \times \frac{P_{CH4}}{100} \tag{8}$$

where, P_{CH4}, the percentage of methane in the biogas; LHV_{CH4}, low heating value of methane (36.3 MJ/m^3 or 10 kW h/m^3).

This value can be converted to kilowatt-hour using a conversion factor of 3.6 million joules per kilowatt hour. Based on the operational capacity of the biogas generator, the necessary biogas flow rate per hour is determined using the following Equation (Omer, 2011):

$$Q_{BG}(t) = \frac{PW_{BG}(t)}{\eta_{E,BG} \times LHV_{BG}} \tag{9}$$

where, $PW_{BG}(t)$, working power of the biogas generators at hour t.

4.2. Total net present cost of biogas system

The total net present cost analysis involves determining the net present value of all anticipated expenses throughout the system's lifespan. The TNPC is expressed by the following formulation:

$$C_{TNPC} = C + OM_{NPV} + F_{NPV} + R_{NPV} - SV_{NPV} \tag{10}$$

where, C_{TNPC}, capital cost; OM, operation and maintenance cost; F, fuel cost; R, replacement cost; SV, salvage value all in $.

The 'NPV' denotes the net present value of each factor.

By considering the power of biogas generators (P_{BG}), the capital cost of investment for the biogas system is obtained as follows:

$$C_{BG} = \gamma_{BG} \times P_{BG} \tag{11}$$

where C_{BG} ($/kW) is the initial cost. The net present value of the total O&M (operation and maintenance) costs in the project lifetime is obtained by:

$$OM_{BG,NPV} = F1_{BG} \times P_{BG} \sum_{i=1}^{N} \left(\frac{1+\mu_{BG}}{1+j_r}\right)^i + F2_{BG} \times PW_{BG}^{yr} \sum_{i=1}^{N} \left(\frac{1+\mu_{BG}}{1+j_r}\right)^i \tag{12}$$

$$F_{BG,NPV} = F3_{BG} \times ABF_r^{yr} \sum_{i=1}^{N} \left(\frac{1+\mu_{BG}}{1+j_r}\right)^i \tag{13}$$

$$SV_{BG,NPV} = \lambda_{BG} \times P_{BG} \times \left(\frac{1+\delta}{1+j_r}\right)^N \tag{14}$$

where, P_{BG}, power of biogas generators; j_r, Interest rate = 10 %; N, project Lifetime = 25 years; δ, Inflation rate = 4 %; μ_{BG}, Escalation rate = 7.5 %; γ_{BG}, initial biogas system cost ($/kW); $F1_{BG}$, Annual fixed operation and maintenance cost of biogas system ($/kW/year) = 0.05*$\gamma_{BG}$; $F2_{BG}$, Variable operation and maintenance cost of the biogas system ($/kW h/year) = 0.0042; $F3_{BG}$, Biomass fuel cost of biogas system ($/t/year) = 45; λ_{BG}, Biogas system resale price ($/kW) = 0.3* γ_{BG}; LHV_{BG}, Low heating value of biogas (kWh/m^3); ABF_{γ}^{yr}, Annual Biomass fuel required.

As a result, using Eq. (10), the total net present cost of the biogas system is obtained.

4.3. Levelized cost of energy

The Levelized cost of energy (LCOE) can be calculated as:

$$LCOE = \frac{C_{TNPC} \times CRF}{E_L} \tag{15}$$

where, E_L, Annual output in kWh; CRF, Capital Recovery Factor.

CRF can be calculated as:

$$CRF = \frac{j_r \times (1+j_r)^N}{(1+j_r)^N - 1} \tag{16}$$

5. System design

5.1. Biomass resource

In the proposed region, the availability of biomass is 3300–5000 tons per day (da Silva et al., 2017; Singh and Chanana, 2019) (Table 5).

5.2. System architecture

The primary focus of the proposed system lies in the biomass power plant, which can provide electricity to both the EV charging station and national grid. The system is designed and simulated using Homer Pro software. Biogas collected from the waste management plant will fuel the biomass power plant. The generated power will be fed into the national grid and supply electricity to an EV charging station for charging electric vehicles. Fig. 2 illustrates the proposed system.

5.3. Load profile for EV charging station

Currently, electric vehicles (EVs) are popular in Bangladesh. There are different types of electric vehicles in Bangladesh, but two of them are very popular: auto rickshaws and easy bikes. They are visible in large cities and small towns. People use it in their daily travel lives.

These EVs can travel a distance ranging from 70 to 120 km, and the energy required per day is approximately 10 kW/day. These vehicles use the utility grid as residential consumers for charging purposes. The EV charging rate was higher than that of residential consumers.

Some specifications of the EVs that are popular and used in Bangladesh are given in Table 6.

Consider 30 typical Auto Rickshaws, each with 1000 W motors, and 6 Easy bikes, each with 1500 W motors. The load daily load profile and yearly load profile are specified in Figs. 3 and 4, respectively.

5.4. Biogas generator

Consider the generator size from 50 kW to 1200 kW, where the 1 kW biogas generator capital cost is $420, replacement cost $380, and operation and maintenance cost is $0.02.

The initial cost of biomass generators is low, but every day procuring 3300 tons of biomass feed and the maintenance and operation of

Table 5
Monthly average available biomass data.

Month	Available biomass (Tons/day)
Jan	3300.00
Feb	3300.00
Mar	3500.00
Apr	3500.00
May	3500.00
Jun	4000.00
Jul	4000.00
Aug	4000.00
Sep	4000.00
Oct	4000.00
Nov	4000.00
Dec	4000.00
Annual	3758.33

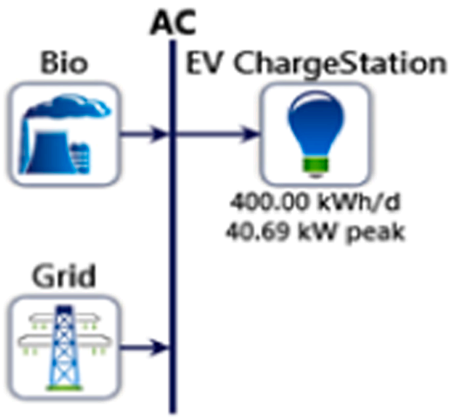

Fig. 2. Proposed system design.

Table 6
Specification of EVs in Bangladesh.

Quantity	Auto rickshaw & easy bike
Power	500–1500 W
Voltage	36/48/60 V
Battery	20–30 Ah
Charging time	6–7 h
Maximum speed	30–40 km/h
Driving distance	70–100 km

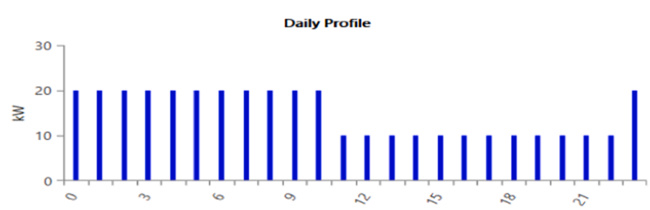

Fig. 3. Daily load profile.

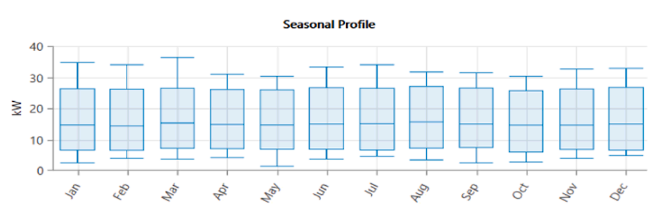

Fig. 4. Seasonal load profile.

biomass for 25 years will be higher. We consider the annual fixed costs and operation costs.

The final optimum generator size is 1200 kW based on the HOMER simulation result. The electrical output generated from the 1200-kW generator is shown in Table 7.

5.5. Fuel consumption

Table 8 outlines the annual fuel consumption of the biogas generator in the proposed system. Additionally, Table 9 provides a summary detailing the biomass consumption.

Table 7
Generic biogas electrical summary.

Quantity	Value	Unit
Electrical production	10,512,000	kWh/yr
Mean electrical output	1200	kW

Table 8
Generic biogas genset (size-your-own) fuel summary.

Quantity	Value	Unit
Fuel consumption	31,536	tons/yr
Specific fuel consumption	2.10	kg/kWh
Fuel energy input	48,810,720	kWh/yr
Mean electrical efficiency	21.5	%

5.6. Grid

Annually, no energy is purchased from the grid, while the energy sold to the grid totals 10,366,000 kWh. Consequently, the approximate annual revenue from selling electricity to the grid amounted to $621,960 (Table 10).

5.7. System costs

Table 11 provides a breakdown of the cost of the proposed system. The capital cost of the biogas generator is approximately $504,000, while there is no cost associated with the grid. Additionally, the combined fixed costs and system operating costs amount to $7.39 million and $5.21 million, respectively.

The annual cost of the overall system is shown in Table 12.

5.8. Electrical output

The generator yields an annual electrical output of 10,512,000 kWh, while the EV charging station's demand is 146,000 kWh per year. As a result, the proposed system is capable of selling approximately 10,366,000 kWh of electricity to the grid annually. Additional information is provided in Tables 13 and 14.

5.9. Economic analysis

Our proposal involves integrating a 1200 kW of generator capacity. This adjustment is anticipated to lower annual operating expenses to $239,602. With this investment, the payback period is estimated at 2.26 years, accompanied by an impressive internal rate of return (IRR) of 45.2 % (Table 15).

6. Results and discussion

6.1. Simulation results

Based on the simulation results conducted using HOMER Pro software and subsequent analysis, the proposed system was evaluated to determine the optimal and cost-effective model for power generation. HOMER was employed to simulate various energy systems and identify the most efficient approach for generating electricity, particularly utilizing renewable biomass sources suitable for the intended environmental conditions.

The simulation outcomes clearly indicate that implementing an efficient biomass generator could significantly enhance electricity generation in Dhaka. The proposed biomass power plant is projected to

Table 9
Biogas consumption statistics.

Quantity	Value	Unit
Total feedstock consumed	31,536	tons
Avg feedstock per day	86.4	tons/day
Avg feedstock per hour	3.6	tons/hour

Table 10
Grid purchase from grid and energy sale to grid.

Month	Energy purchased (kWh)	Energy sold (kWh)	Net energy purchased (kWh)	Peak load (kW)	Energy charge (kWh)	Demand charge (kWh)	Total (kWh)
January	0	880,510	−880,510	0	($52,831)	$0.00	($52,831)
February	0	795,551	−795,551	0	($47,733)	$0.00	($47,733)
March	0	880,105	−880,105	0	($52,806)	$0.00	($52,806)
April	0	851,945	−851,945	0	($51,117)	$0.00	($51,117)
May	0	880,689	−880,689	0	($52,841)	$0.00	($52,841)
June	0	851,836	−851,836	0	($51,110)	$0.00	($51,110)
July	0	880,515	−880,515	0	($52,831)	$0.00	($52,831)
August	0	879,949	−879,949	0	($52,797)	$0.00	($52,797)
September	0	851,866	−851,866	0	($51,112)	$0.00	($51,112)
October	0	880,456	−880,456	0	($52,827)	$0.00	($52,827)
November	0	852,262	−852,262	0	($51,136)	$0.00	($51,136)
December	0	880,315	−880,315	0	($52,819)	$0.00	($52,819)
Annual	0	10,366,000	−10,366,000	0	($621,960)	$0.00	($621,960)

Table 11
Net present costs.

Parameter	Generic biogas genset (size-your-own)	Grid	Other	System
Capital	$504,000	$0.00	$700,000	$1.20M
Operating	$3.52M	-$10.4M	$6.69M	($196,016)
Replacement	$4.28M	$0.00	$0.00	$4.28M
Salvage	($79,735)	$0.00	$0.00	($79,735)
Resource	$0.00	$0.00	$0.00	$0.00
Total	8.22M	-$10.4M	$7.39M	$5.21M

Table 12
Annualized costs.

Parameter	Generic biogas genset (size-your-own)	Grid	Other	System
Capital	$30,135	$0.00	$41,854	$71,988
Operating	$210,240	($621,960)	$400,000	($11,720)
Replacement	$256,090	$0.00	$0.00	$256,090
Salvage	($4767)	$0.00	$0.00	($4767)
Resource	$0.00	$0.00	$0.00	$0.00
Total	$491,697	($621,960	$441,854	$311,591

Table 13
Electricity produced by generator.

Component	Production (kWh/yr)	Percent
Generic biogas genset	10,512,000	100
Total	10,512,000	100

Table 14
Electricity consumption.

Component	Consumption (kWh/yr)	Percent
AC Primary Load	146,000	1.39
Grid sales	10,366,000	98.6
Total	10,512,000	100

Table 15
Economic analysis.

Parameter	Value
Simple payback (yr)	2.26
Return on Investment (%)	31
Internal Rate of Return (%)	45.20
Total Net Present Cost ($)	5,211,338
Levelized Cost of Energy ($/kWh)	0.0296
Capital Investment ($)	504,000
Annualized Savings ($)	173,100

produce approximately 10,512 MWh annually, with a specific fuel consumption rate of 2.10 kg/kWh.

Additionally, the power consumption of EV charging stations constitutes approximately 1.39 % of total consumption. No energy is purchased from the grid annually, while 10,366,000 kWh of surplus energy is sold back to the grid, resulting in an estimated annual revenue of $621,960 from electricity sales. Consequently, the proposed system is expected to save approximately $173,100 with a payback period slightly exceeding 2.26 years, after which the project is anticipated to generate profits throughout its operational lifespan.

6.2. Environmental aspects of the proposed system

Biomass could significantly reduce the greenhouse gas emission with around 65 % by 2050 (Ionescu et al., 2019). It is estimated that the bioenergy potential from crops/organic residues, agricultural and forestry waste account a total average of 6.2–22.1 EJ/year in the European Union and 56.2 EJ/year worldwide (Ionescu et al., 2019).

The global warming potential of waste to energy technology is estimated to reduce global greenhouse gas emissions by 17–22 % through integrated waste management based on the 3R (recycle, reduce, reuse) principle (Yusuf and Kusumah, 2022).

Biogas derived from waste materials not only mitigates pollution and unpleasant odors but also produces slurry that acts as a fertilizer, improving soil quality and environmental cleanliness. Household waste, vegetable market waste, and byproducts from industries such as cotton stalks, leather, pulp, and paper can be efficiently converted into energy through biogas production, fermentation, or cogeneration processes.

This approach not only charges electric vehicles (EVs) but also supplies renewable electricity to the grid, highlighting its environmental benefits and cost-effectiveness.

In our proposed system, electricity is generated using biogas and biomass, effectively reducing CO_2 emissions by utilizing biogas resources. The utility grid in Bangladesh primarily depends on fossil fuels and the rate of CO_2 emissions are approximately equal to 640 g/kWh (Karmaker et al., 2020). Based on the simulation result, in the proposed model, yearly CO_2 emissions is about 5682 kg, whereas the same demand grid-based system produces 92,272 kg of CO2. Therefore, the proposed model reduces CO_2 emissions by approximately 93.7 % compared to the grid-based system. So, by harnessing waste for energy generation, this approach contributes significantly to pollution reduction, climate mitigation, and economic opportunities globally.

Therefore, the integration of biogas and biomass for electricity generation and EV charging not only enhances waste management practices but also fosters sustainable development and environmental stewardship.

6.3. Socio-economic benefits of the proposed system

In Bangladesh, a typical *Easy Bike* driver earns around $18 to $25 daily, whereas the energy consumption cost of this vehicle is only $1 to $1.25 per day (Karmaker et al., 2020). This presents a lucrative income opportunity for many individuals as it reduces physical labor and saves transportation time. Owing to the large city population and narrow roads, the demand for this vehicle is also increasing. Furthermore, if the proposed charging station charges the EVs, the charging cost for an Easy Bike will be lower than the current cost and will also contribute to decreasing the theft of electric energy from the government resources.

7. Conclusions

In Bangladesh, over 58 % of waste is currently mismanaged, leading to substantial environmental pollution. However, with effective management of the total waste (4,866,504.85 tons/year), we have the potential to generate approximately 2765.33 MW of electricity (Hasan et al., 2023). This could significantly alleviate our national energy crisis. While there are challenges to address in the waste-to-energy conversion process, these dependencies can be overcome with proper planning and implementation.

Ensuring the success of waste-to-energy generation involves carefully considering several key factors. These include the technological choices, economic feasibility, and the social and environmental impacts throughout the plant's design and implementation phases. The long-term sustainability of the project heavily depends on gaining social acceptance, underscoring the importance of involving local communities in the plant's development within their vicinity.

Our proposed biomass system presents a promising alternative to traditional power generation methods, utilizing locally available waste materials to provide a versatile energy solution. Furthermore, the proposed charging station not only alleviates strain on Dhaka's national grid by facilitating electric vehicle charging but also enhances grid reliability and quality while reducing energy theft. However, the efficiency of biogas production was not addressed in the proposed research. Future studies on biomass energy should prioritize critical factors such as land use changes, biodiversity impacts, and water usage. Thorough investigations into the environmental implications of various biomass feedstocks and conversion methods are crucial. Additionally, research needs to evaluate the feasibility of adopting biomass energy across diverse regions and countries, considering variations in biomass resources, policy frameworks, and energy requirements.

Currently, biomass electricity generation lags behind solar and wind energy in utilization, yet future projections anticipate its growth due to its stable output compared to the fluctuating nature of solar and wind energy. Biomass energy holds significant potential for advancing rural electrification and industrialization, contingent on adequate guidance and infrastructural support.

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CRediT authorship contribution statement

Akib Chowdhury: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Nusrat Chowdhury:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Wahiba Yaïci:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Michela Longo:** Writing – review & editing, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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