An Incineration Methodto Produce Energyfrom Wastein Rajshahi City, Bangladesh

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Abstract

The Rajshahi City Corporation generates a significant quantity of municipal solid waste each day, but it does not have an effective waste management system. Additionally, Rajshahi has an inadequate supply of electrical power with an increasing population. This study aims to investigate the energy potential of the municipal solid waste of Rajshahi by incineration and to check the feasibility of the incineration process. The calorific values of municipal solid waste were determined by using a variety of empirical formulae, with the data on the proximal and ultimate analysis serving as inputs. The energy potential of the incineration process was determined using the calorific value, and after that, a cost study for the incineration plant was carried out in order to determine whether or not it would be feasible. It was discovered that the municipal solid waste had a calorific value of 6576.36 kcal/kg, giving it an energy potential of 35.91 MW for the process of incineration. The findings of the research also indicate that the burning of solid waste is a viable option with a payback time of nine years. Incineration as a kind of waste-to-energy conversion presents a potentially workable solution for the management of municipal solid waste and the fulfillment of Rajshahi's need for power. Also, it can be a sustainable way to generate energy from municipal solid waste and reducing the dependency on fossil fuels which causes harm to environment, eco-system, and human beings.

Keywords
waste to energy, incineration, electricity, municipal solid waste, waste management, feasibility, sustainable energy and sustainability.

1. Introduction
With the population's growth, energy demand is also growing, and the generation of waste is increasing massively. Municipal solid waste (MSW) is accumulating at a rate that is increasing even higher than the growth of urbanization due to human society's desperate rush toward industrial development on a global basis. Only a small amount of this waste goes through proper waste management. The rest is either dumped or openly burnt, which negatively impacts the local environment and human health. Countries like Germany, Denmark, Sweden, Netherlands, UK, Indonesia, Malaysia, Japan, China, Korea & USA are focusing more on converting their MSW into valuable heat and energy through the waste treatment process. A waste treatment process that generates energy in the form of electricity, heat, or transport fuels is considered waste to energy (WtE). In the 2009 report "Towards a Clean Energy Infrastructure," WtE is highlighted as one of eight technologies with great potential to contribute to a future low-carbon energy system.The two most prevalent WtE techniques are MSW incineration and landfill gas recovery technology(Tan *et al.* 2014), although MSW incineration is the most economically efficient alternative for the future energy system(Münster e Meibom 2011). In over 40 nations, more than 800 WtE incineration plants are operational.

Bangladesh is the eighth most densely populated country, with an area of 1,47,570 square km and a population of 165 million. Proper waste management is still a dilemma in every city in Bangladesh, including Rajshahi City Corporation (RCC). It had a population of 0.9 million in 2011 and a population density of around 8,700 per square kilometer. The population is growing at a pace of 0.86 percent(Bangladesh Bureau of Statistics 2022). Currently, about 50–60 percent of municipal solid waste is landfilled, with the remainder recycled by informal sectors, self-disposal in residential areas, on highwaysand drains. It is becoming complex daily as more land is required for trash disposal. Several studies have been done on the Rajshahi waste management system(Alam e Qiao 2020; Halder *et al.* 2014), its fault and many ways of converting waste into energy(P. Das *et al.* 2019; Habib *et al.* 2021). Some studies are conducted that measure electricity generation potential(Islam 2016). However, no studyis done on incineration as WtE method in RCC.A large portion of Bangladesh's energy comes from fossil fuels, making the country vulnerable to future energyshortages. Additionally, to address this energy shortfall scenario, the government of Bangladesh has announced plans to decrease gas-based electricity output and progressively switch to coal-fired power plants, which would undoubtedly raise the national carbon footprint. WtE for MSW management in Bangladesh can be a practical strategy for producing both renewable and non-renewable energy.

1.1 Objectives

1. Calculating the calorific value of wastage in Rajshahi and recoverable energy for electricity generation.
2. Doing a feasibility study to determine how much it would cost for a waste to electricity plant and the time it would take for the plant to pay for itself.

2. Literature Review

Rajshahi city is by the bank of the Padma River and is among the largest divisional towns in Bangladesh(B. K. Das et al. 2014). The city is between 24.05' and 25.14' north latitude and 88.09' and 89.25' east longitude. With an area of 96.96 square kilometres, the city corporation was incorporated in 1987(Halder et al. 2014). 0.85 million people live in Rajshahi city. Bangladesh's urban population is growing at a pace of 6 percent per year and is primarily centred in six main cities, including Rajshahi (Habib et al. 2021). Due to increased population expansion, the amount of municipal solid waste (MSW) is increasing."Municipal Solid Waste" (MSW) is substances thrown away from homes, businesses, or components that are no longer useful to the person who owns them(Vergara e Tchobanoglous 2012). The residents of the RCC generate 400 tons of garbage every day. Less than 50% of the wards have door-to-door waste collection services (Halder et al. 2014). Observations indicate that household solid waste accounts for about 77.18 percent of the total MSW produced in RCC(Habib et al. 2021). There are 35 secondary collection points and one final disposal site in Nowdapara(Islam 2016). Due to improper waste disposal, the environment is getting unsafe.

Calorific value is a way to determine how much energy is in solid waste by measuring how much heat it gives off when wholly burned. When building incinerators to recover energy from MSW, it is crucial to know the calorific value(Komilis et al. 2012). Mathematical models can be used to determineheat they give off by using empirical formulae which employs data from the fuel's physical composition and proximateanalysis(P. Das et al. 2019). Waste to Energy (WTE) generates electricity or heat energy by steam generated from burning MSW. It is estimated that the energy potential from MSW in RCC is 5.336 MW in 2012, 6.205 MW in 2015, 8.201 MW in 2020, and 10.568 MW in 2025(Saifullah 2015). Another study(B. K. Das et al. 2014) found that the energy potential of MSW in 2020 is 7.6 MW by landfilling(Sarkar et al. 2015). The electricity demand of RCC was 65 MW, while only 25 MW was supplied, according to Halder et al. (2014). Hence WTE can be a sustainable approach to meet the needs of RCC's electricity and reduce environmental hazards. Kaza e Bhada-Tata (2018)states that developing countries need more investment costs for WtE plants, but it requires less operational cost. Because these countries have high labor availability and low labor cost. Alkishriwi (2021)conducted a feasibility analysis in Tripoli city, Libya, resulting in a payoff period of 9.6 years. Karlsson e Jönsson (2012) have done a pre-feasibility study for an incineration plant in Chisinau, Moldova. Their estimated investment cost was about 145 million euros, and they have a payoff period of 5-6 years(Karlsson e Jönsson 2012).So, it is seen that establishing an incineration plant for converting waste to energy is advantageous in every possible way.

3. Methods

In this research, we have aimed to determine the electric potential of Rajshahi's municipal solid waste and the feasibility of a WtE plant to extract that electricity from waste. Multiple processes were followed to reach the goal which is given in the flowchart below Figure 1.

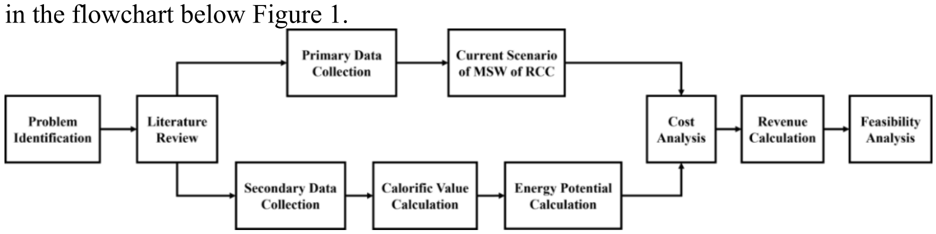

Figure 1.Flowchart of methodology.

The calorific value of MSW tells us how much fuel we'll need to burn it and how much power we'll get back from it. Many works of literature are accessible with models and empirical formulae to determine calorific value. Some of the empirical equations discovered in the literature are listed in Table 1.

Table 1. Summary of literature for predicting calorific value.

Equation No.	**Equation**	**Units**	**Reference**
	Ultimate Analysis		
1	Dulong's HHV = 80C + 80.345(H – O/8) + 22.40S	Kcal/kg	(Kathirvale *et al.* 2004)
2	HHV = 0.3491C + 1.1783H + 0.1055S – 0.1034O – 0.0151N – 0.211A	MJ/kg	(Channiwala e Parikh 2002)
3	HHV = 0.3278C + 1.4119H + 0.09257S −0.1379O + 0.637	MJ/kg	(Given *et al.* 1986)
	Proximate Analysis		
4	HHV = 0.03A − 0.11M + 0.33VM + 0.35FC	MJ/kg	(Majumder *et al.* 2008)
5	HHV = 0.3536FC + 0.1559VM − 0.0078A	MJ/kg	(Parikh *et al.* 2005)
6	HHV = 0.196FC + 14.119	MJ/kg	(Demirbas 2016)

HHV = Higher Heating Value; C = Carbon; O = Oxygen; H = Hydrogen; N = Nitrogen; S = Sulphur; A = Ash; VM = Volatile Matter; FC = Fixed Carbon; M = Moisture.

To determine the feasibility of a waste incineration plant in Rajshahi, three types of cost was calculated. They are the initial investment, fixed cost and variable cost. Variable cost consists of operation and maintenance cost, transportation cost. The possible revenue of the plant was calculated and finally the pay off period was determined using,

Pay Off = Investment Cost / {Revenue – (Fixed Cost + Variable Cost)}

Either the plant will be feasible or not was shown by this pay off period calculation. The overall researchwas conducted by using these methodologies.

4. Data Collection

We have collected primary data from the chief cleaning officer of the conservation unit, Rajshahi City Corporation. At the same time, secondary data was collected from different research papers related to Rajshahi waste composition and management. Data on the number of vehicles was collected from the RCC authority and is given in Table 2.

Table 2. Vehicle used for waste collection in RCC. (RCC Authority)

Vehicle	**Amount**
Truck	14 (3 MT)
Tractor	6 (6 MT Double Trolley)
Rickshaw Van - Central	70
Rickshaw Van – Ward wise	187

There are 29 secondary transfer stations in Rajshahi, three of which are modernized. An average day at RCC generates 400-450 MT of solid waste, around 320-360 MT of that total being collected. The physical characteristics data of the MSW was collected from the RCC Authority and is illustrated in Figure 2.

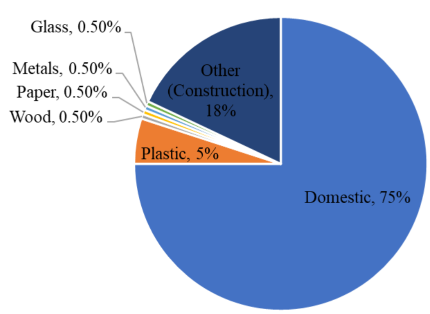

Figure 2. Characteristics of waste in RCC. (RCC Authority)

The domestic component accounts for 75 percent of RCC's MSW, an enormous amount since a significant section of the population consists of students. 18% of the garbage has components that originate from different building sites. The contribution of plastics, metals, wood, glass, and paper is relatively low, at just 5% each. Waste from home, including wood, paper, and food scraps, may be burned safely and effectively. However, it is essential to note that the municipal solid waste included in RCC has a significant percentage of moisture, and the plant might benefit from preheating technology.

5. Results and Discussion

5.1 Energy Potentialof MSW of RCC by Incineration

The determination of the energy potential of MSW requires an accurate calorific value calculation. The equations from Table 1are used to determine the calorific value of MSW in Rajshahi city. The results are shown in Table 3, and the calorific value is given in kcal/kg as the unit of measurement.

Table 3. Calorific Value of MSW in Rajshahi City.

Equation No.	Calorific Value	Unit
1	4918.89	Kcal/kg
2	5246.88	Kcal/kg
3	5299.43	Kcal/kg
4	6576.36	Kcal/kg
5	6160.52	Kcal/kg
6	5810.47	Kcal/kg

In table 3, Equations 1,2 and 3 utilized data gained from the ultimate analysis, whereas equations 4,5 and 6 used data collected from the proximal analysis. The calorific value determined using the proximal data is greater than that of the ultimate data. Figure 3 displays a graph of the caloric values generated from the equations and the standard deviation of the values relative to the mean value.

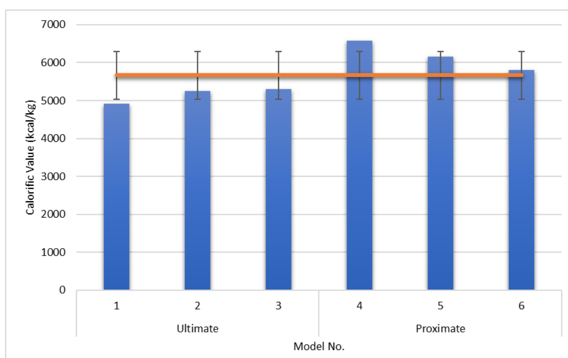

Figure 3. Deviation of the calorific values from the mean.

Figure 3 shows that the calorific value per kilogram is 5668.76 kcal. 626.5 kcal/kg is the standard deviation for the calorific values. The mean value is used in subsequent computations since all the values are close to the mean and distributed uniformly.The potential energy recovery from municipal solid waste during the incineration process was determined using a straightforward calculation. It has been speculated that the waste incinerator would only operate at a 30 percent efficiency rate. The data was tabulated and may be seen in Table 4.

Table 4. Energy potential of MSW of RCC.

Incineration Plant Efficiency	Working Hour Per Year	Waste Per Day (MT)	Waste Per Year (MT)	Calorific Value of Fuel (MJ/Kg)	Calorific Value of Fuel (MJ/MT)	Calorific Value of Fuel (kwh/ton)	Specific Output (kwh/ton)	Energy Potential (MW)
30	8030	400	146000	23.7	23700	6583.3386	1975.00158	35.90911964

When MSW is incinerated, it gives off 35.91 MW of potential energy. In RCC, burning MSW could be an excellent way to get power.

5.2 Energy balance

The plant is fed with a sufficient amount of water through the boiler pipe into the combustion chamber. Thus, steam is created through the burning of waste materials. High- and low-pressure condenser turbines are used to extract the steam from the condensate in a regulated manner. This steam is cooled separately so it can be fed again as input water on a circular basis. The plant itself consumes a certain amount of electricity for its machinery which can be collected from the electricity it is producing. The specific electrical energy consumption is about 27% of its produced electricity which is about 0.0243 MW/t_{msw}(Tsai 2019). As the produced electricity will be 35.91 MW, so the electricity consumption is 9.72 MW and Net electricity is 26.189 MW.

5.3 Capacity

From our collected data it was learned that the average waste production rate of Rajshahi City Corporation is 400-450 metric tons (MT) per day. So annual waste production is around (400×365) =146,000 MT/year. We conducted our research considering a 150,000 MT/year capacity incineration plant for the conditions of Rajshahi.

5.4 Location and Area

Municipal waste of Rajshahi is dumped at Nowdapara, a dumpsite with a total size of 6.457 hectares. This is where our WtE plant will be located because it already has the necessary transportation infrastructure and municipal authorities. The average plant size per ton of waste is 0.0071 ha/unit waste(Tsai 2019). As a result, our WtE Plant will have a 2.82-hectare plant size.

5.5 Initial cost

Depending on the design of the WtE plant, the investment costs might significantly vary. Roads, a mixing area, and a waste storage facility must be built. It is estimated to cost 18 crore BDT to make the roadways and foundations for garbage storage. The combustion chamber-steam generator should contain:i) coal, waste, and other materials feeding system, ii) combustion air supply, iii) a steam generator that takes feed water as input and produces steam as output side, iv)a moving grate combustion chamber, v) flue gas pipes that provide heat to the feed-water heaters.

For a 150,000 t/year WtE plant capacity, the combustion system is expected to cost 76 crore BDT without construction cost and control equipment. The water and steam system components include:i) a water treatment facility, ii) a steam extraction control system, iii) a condensation turbine, iv) an air-cooled condenser.

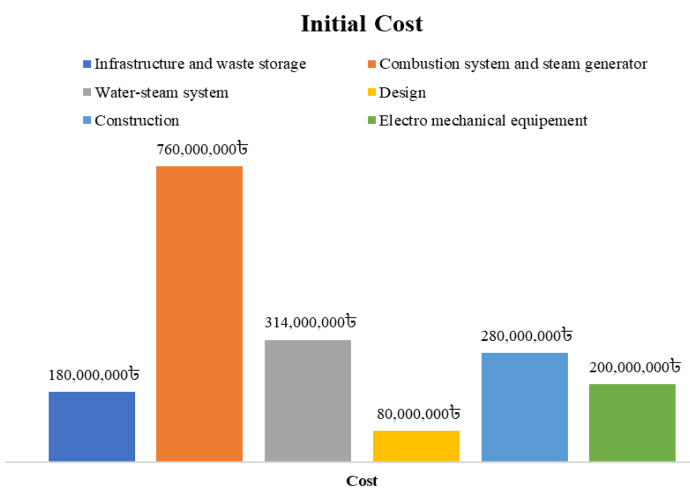

Figure 4. Initial investment of WtE plant in Rajshahi.

Figure4(“Best Available Techniques (BAT) reference document for waste incineration - Publications Office of the EU” 2018) provides the overall cost of the WtE plant's components, excluding the flue gas cleaning system (which is analyzed further in the report), including the expenses of construction, design, and electro-mechanical installations. Total initial cost is 1,81,40,00,000 BDT.

5.6 Cost of flue gas cleaning system

A flue gas cleaning system combines a particle filter, flue gas treatment, and NO_x reduction system. It mainly cleans the output air, which is safer for the environment. Cleaning flue gas is an essential part of incineration process. We have considered two variations for Rajshahi's waste composition.

5.6.1 Variation 1

The first variation is the combination of:i)SNCR system, ii)Semi-dry flue gas treatment, iii)Wet scrubber & Bag filter which is shown in Figure 5.

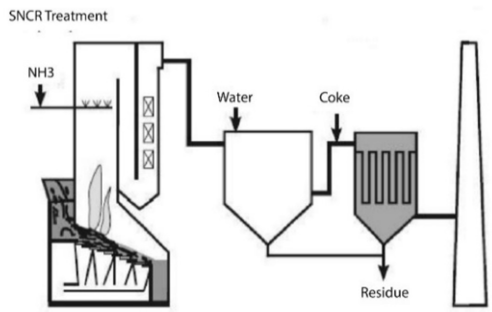

Figure 5.Variation 1 of flue gas system.

Flue gases are first sprayed with water in the SNCR system to remove the acid compounds (NH3), resulting in N2 as residue. Activated coke and powdered calcium hydroxide are fed into the flue gas before it enters the semi-dry treatment. It removes SO_2, HCl, HF, and mercury from the flue gas. The bag filter removes the calcium salts from the solution. The estimated cost of this variation is given below in Table 5:

Table 5.Investment cost of variation 1

Component	Cost (BDT)
SNCR system	2,40,00,000
Semi-dry treatment	8,00,00,000
Bag filter	2,50,00,000
Total	**12,90,00,000**

5.6.2 Variation 2

The second variation is the combination of:i) A wet flue gas treatment system, ii) SCR system, iii) Electrostatic precipitator and wet scrubber which is shown in Figure 6.

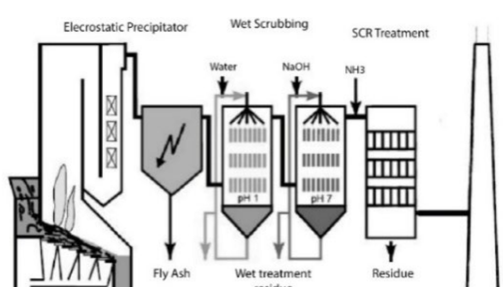

Figure 6.Variation 2 of flue gas system.

An electrostatic precipitator purifies flue gases emitted by the steam generator. A wet scrubber is then used to remove mercury and acid compounds from the flue gas, followed by another wet scrubber with sodium hydroxide to remove sulfur oxides. Finally, the selective catalytic reduction system is used to lower the amount of NO_X in the flue gases.The overall cost of this variation is given below in Table 6:

Table 6. Investment cost of variation 2

Component	Cost (BDT)
Wet treatment	1,00,00,000
Electrostatic precipitator	80,00,000
SCR system	1,40,00,000
Total	**3,20,00,000**

5.7 Operation and maintenance cost

For proper operation, the plant will need water supply, coal, ammonia (NH_3), Calcium hydroxide ($Ca(OH)_2$), and reagent for wet treatment (NaOH). The Table 7 shows the amount of these reagents according to our plant's need and the yearly cost.

Table 7. Operation cost for both variations.

Type of cost	Need	Price	Variation 1 (BDT)	Variation 2 (BDT)
Process water	2 m^3/t_{msw}(Gardoni *et al.* 2015)	40 bdt/m^3	1,16,80,000	1,16,80,000
Coal	6.8493×10^{-4} t/t_{msw}	12000 bdt/t	12,00,000	12,00,000
Reagent for SNCR (NH_3)	1.37×10^{-5} t/t_{msw}	180 bdt/kg	3,60,000	-
Reagent for SCR (NH_3)	6.8493×10^{-6} t/t_{msw}	180 bdt/kg	-	1,80,000
Reagent for semi-dry system ($Ca(OH)_2$)	2.055×10^{-3} t/t_{msw}	18 bdt/kg	54,00,000	-
Reagent for wet treatment (NaOH)	7.534×10^{-6} t/t_{msw}(SCHNEIDER *et al.* 2010)	1300 bdt/kg	-	14,30,000
Total			**1,86,40,000**	**1,44,90,000**

The amount of waste going through the system affects how much it costs to keep the combustion system and steam generator in good shape. When the amount of waste goes up, the cost of ash disposal also goes up. Residues that should be disposed of are bottom ash, flying ash, bag filter and wet treatment residues, heavy metals, etc.For calculation, **Maintenance cost**= [0.0075 × (MSW Input in MT/day)] % × Cost of flue gas treatment(Kim e Jeong, 2017). Maintenance cost was found 38,70,000 BDT and 9,60,000 BDT respectively for variation1 and variation 2.

5.8 Transportation cost

According to our collected data, Rajshahi City Corporation has 4 thanas, 170 mahallas, and a population density of4068 per sq km. As we considered our plant location in Nowdapara, the GPS distance from four thanas to Nowdapara is shown in Table 8.

Table 8.GPS distance from thanas to Nowdapara.

Thana	Area (sq km)	Ward	Mahalla	Population	Density (per sq km)	Center Point	Distance from Nowdapara (km)
Boalia	38.11	16	82	191711	695	Ward 13	5.5
Rajpara	24.90	9	46	121076	4862	Court station	8.2
Matihar	20.32	5	20	51724	2545	Meherchondi	6.2
Shah Makhdum	12.23	3	22	24300	1986	Khirshin	4.1

As our WtE plant will collect the daily generated waste of Rajshahi City Corporation, the existing vehicles as shown in Table 2,were distributed among the four thanas depending on their area and population density which is shown in Table 9.

Table 9. Vehicle distribution for waste transportation.

Region	Truck (1 truck/6 sq. km)	Tractor (1 tractor/12 sq. km)	Van (2 van/sq. km)
Boalia	6	3	76
Rajpara	4	2	50
Matihar	3	2	41
Shah Makhdum	2	1	25
Total	**15**	**8**	**192**

The loading costis taken 100 BDT/month for each van. The total transportation cost is determined by "From-To matrix"(Kim e Jeong 2017) between each region and Nowdapara, taking diesel consumption 0.085litre/km for truck, 0.125litre/km for tractor and diesel cost 80 BDT/litre.

Transportation cost= Number of required vehicles × Distance between start and end × Fuel consumption × Fuel price × Loading cost

Table 10. Cost of transportation.

Region	Loading cost/month (BDT)	Transportation cost/delivery/month (BDT)
Boalia	7,600	2,05,394
Rajpara	5,000	3,28,827
Matihar	4,100	3,22,533
Shah Makhdum	2,500	1,73,567
Total		**10,30,320**

As the trucks have 3 tons of capacity, and the tractors have 6 tons of capacity, so for single delivery (15×3)+(8×6) or approximately 100 tons of waste will be delivered to the plant. So, it will need four delivery a day to deliver regularly generated 400 tons of waste. Then the total yearly transportation cost is (1030320×4) = 41,21,281 BDT and yearly cost is (1030320× 4 ×12) = 49,455,370 BDT.

5.9 Worker's salary

It is considered that the plant will be operational 22 hours a day. So, it will have three shifts and run seven days a week. The required personnel, their salary, and annual total salary per shift (SCHNEIDER *et al.* 2010) are given in Table 11.

Table 11. Required personnel and annual salary.

Personnel	Required number	Average Income (BDT)	Salary/shift/year (BDT)
Manager	1	50,000	6,00,000
Engineer	5	75,000	45,00,000
Maintenance	3	16,900	6,08,400
Worker	15	8,000	14,40,000
Total			**71,48,400**
For 3 shifts			**2,14,45,200**

5.10 Revenue Analysis

i) Revenue from waste collection: The raw material needed as input in our plant is the waste that is generated daily in Rajshahi. For proper management, the waste collection service will be chargedat 1 BDT/kg.

ii)Revenue from selling electricity: The most important revenue that would be earned by the plant is selling the electricity. As we are generating electricity from a renewable source,12 BDT/KW will be charged.

iii)Revenue from selling residues: The plant will produce a large amount of fly ash (5475 MT/year) daily. Fly ash is used in construction work and in cement factories. Bangladesh imports fly ash currently from India and other neighboring countries. So, our plant can contribute a small amount of fly ash and make revenue from it. Fly ash will be sold at the local price of 550 BDT/MT.Another residue is metals or iron which remains unburned after the waste combustion. As seen from Figure 1, Rajshahi's waste contains 0.5% metal. A ton of metal is 22000 BDT at the local market.

5.11 Pay off period

Payback time is the time when our initial investment will be paid off. The calculation is done for both variations of the plant we discussed earlier. Our plant has a lifetime of 30 years, so we have forecasted Rajshahi's population till the year 2023-2052.The data of population of RCC from 1950 to 2022 was taken from PopulationStat (2022). After that exponential smoothing forecasting was done to find out the population from 2023 to 2052. These data are shown in Figure7.

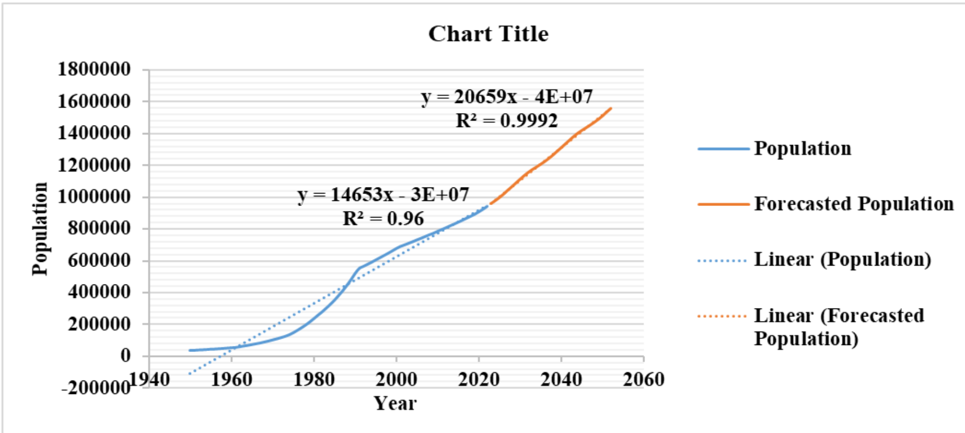

Figure 7. Forecasted population of RCC

As the population of Rajshahi is increasing yearly, waste generation is also increasing. Calculated waste production rate per person is 0.4246 kg/day. Pay off period and profit over a lifetime are shown in Table 12 and Table 13.

Table 12.Pay-off period and profit over the lifetime for variation 1

Year	Waste/year (MT)	Net Electricity/ year (MW)	Fixed Cost (BDT)	Variable Cost (BDT)	Revenue (BDT)	Pay Off (BDT)
2022	146000	9560	1950148400	72588575	279778825	-1742958149
2023	148475	9720	7148400	73818495	284519325	-1539405722
2024	151270	9905	7148400	75207850	289874325	-1331887646
2025	154270	10100	7148400	76701080	295629690	-1120107434
2026	157600	10320	7148400	78356980	302012035	-903600777.1
2027	161310	10560	7148400	80200510	309117585	-681832103.4
2028	164806	10790	7148400	81938940	315818020	-455101421.2
2029	168515	11035	7148400	83782085	322922085	-223109822.2
2030	172155	11270	7148400	85592330	329899330	14048776.1 **Pay off period**
2031	175765	11510	7148400	87386470	336814500	256328404.8
2032	178990	11720	7148400	88990355	342996365	503186014.2
2033	181785	11900	7148400	90379865	348351960	754009711.4
2034	184275	12065	7148400	91618490	353126020	1008368840
2035	186875	12235	7148400	92911830	358110955	1266419561
2036	189670	12420	7148400	94301190	363465955	1528435931
2037	192675	12615	7148400	95794415	369221320	1794714437
2038	196000	12835	7148400	97450315	375603665	2065719389
2039	199715	13075	7148400	99293850	382709215	2341986356
2040	203210	13305	7148400	101032275	389409650	2623215333
2041	206920	13550	7148400	102875500	396514015	2909705446
2042	210560	13785	7148400	104685670	403490960	3201362338
2043	214165	14025	7148400	106479810	410406130	3498140261
2044	217395	14235	7148400	108083695	416587995	3799496165
2045	220190	14415	7148400	109473200	421943590	4104818156
2046	222680	14580	7148400	110711830	426717650	4413675578
2047	225280	14750	7148400	112005170	431702585	4726224594
2048	228075	14935	7148400	113394525	437057590	5042739258
2049	231080	15130	7148400	114887755	442812955	5363516059

2050	234410	15350	7148400	116543650	449195300	5689019304
2051	238120	15590	7148400	118387185	456300850	6019784566
2052	241615	15820	7148400	120125615	463001285	6,35,55,11,837 **Profit over lifetime**

Table 13.Pay-off period and profit over the lifetime for variation 2

Year	Waste/year (MT)	Net Electricity/ year (MW)	Fixed Cost (BDT)	Variable Cost (BDT)	Revenue (BDT)	Pay Off (BDT)
2022	146000	9560	1853148400	65527950	279778825	-1638897526
2023	148475	9720	7148400	66638240	284519325	-1428164842
2024	151270	9905	7148400	67892450	289874325	-1213331369
2025	154270	10100	7148400	69240435	295629690	-994090514
2026	157600	10320	7148400	70735265	302012035	-769962146
2027	161310	10560	7148400	72399480	309117585	-540392443
2028	164806	10790	7148400	73968810	315818020	-305691637
2029	168515	11035	7148400	75632680	322922085	-65550632
2030	172155	11270	7148400	77266845	329899330	179933452 **Pay off period**
2031	175765	11510	7148400	78886470	336814500	430713082
2032	178990	11720	7148400	80334345	342996365	686226700
2033	181785	11900	7148400	81588700	348351960	945841565
2034	184275	12065	7148400	82706845	353126020	1209112340
2035	186875	12235	7148400	83874385	358110955	1476200510
2036	189670	12420	7148400	85128600	363465955	1747389465
2037	192675	12615	7148400	86476585	369221325	2022985805
2038	196000	12835	7148400	87971415	375603665	2303469660
2039	199715	13075	7148400	89635625	382709215	2589394850
2040	203210	13305	7148400	91204960	389409650	2880451140
2041	206920	13550	7148400	92868895	396514015	3176947860
2042	210560	13785	7148400	94502990	403490960	3478787425
2043	214165	14025	7148400	96122615	410406130	3785922540
2044	217395	14235	7148400	97570490	416587995	4097791645
2045	220190	14415	7148400	98824845	421943595	4413761995
2046	222680	14580	7148400	99942995	426717655	4733388255
2047	225280	14750	7148400	101110530	431702585	5056831900
2048	228075	14935	7148400	102364745	437057590	5384376355
2049	231080	15130	7148400	103712730	442812955	5716328180
2050	234410	15350	7148400	105207560	449195300	6053167520
2051	238120	15590	7148400	106871775	456300850	6395448190
2052	241615	15820	7148400	108441105	463001285	6742859970 **Profit over lifetime**

As it can be seen that both variations have a pay-off period of 9 years, and it is in the year 2030. The company gains profit for the next 21 years.

5.12 Results

From our analysis, we find that both plant variations are relatively close to each other. Table 14shows a summarized result for the initial year, which is proportionately the same for future years.

Table 14.Summary of analysis.

Basic Data	Variation 1	Variation 2	Unit
Capacity	1,50,000		MT/year
Electric power	35.909		MW/day
Electricity consumption	9.72		MW/day
Working hours	8000		hr/year
Lifetime	30		year
Initial investment	1,94,30,00,000	1,84,60,00,000	BDT
Selling price of electricity	12		BDT/KW
Collection price of waste	1		BDT/kg
Selling price of metal	22000		BDT/ton

Selling price of fly ash	550		BDT/ton
Pay off period	9	9	year
Profit over lifetime	6,35,55,11,837	6,74,28,59,970	BDT

By comparing two variations according to the waste composition of Rajshahi, we have found that variation 2 has a comparatively lower initial investment and higher profit over a lifetime than variation 1. Though both variations have the same payoff period, variation 2 has a lower influence over the environment. Finally, we can say that constructing a WtE plant in Rajshahi is feasible because the total profit is about four times the initial investment.

6. Conclusion

In this work, waste generation and physical composition data of Rajshahi City Corporation were collected, and it was found that waste generation is 400 MT per day. The calorific value was determined by several formulas, the mean was about 5670 kcal, and electricity potential was determined at about 35 MW/day. Therefore, it was suitable for the WtE project and incineration method was chosen for plant type. After calculating different fixed and variable costs for two verities of plant, it was found that the best variant has an initial cost of 1.84 billion BDT which pays off in 9 years, and the plant has a lifetime profit of 6.74 billion BDT which is about four times of its investment. So, it can be seen clearly that a WtE plant is very much feasible and necessary for RCC. It can create a revolution in Bangladesh by reducing waste and using waste as a renewable energy source. Though this type of incineration plant has shown a higher pay off period and initial cost than other types of renewable energy plant like anaerobic digestion, gasification, and landfilling, the incineration plant is more profitable and eco-friendlier. Finally, it can be said that the “Waste to Energy” concept must be given priority.

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