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Climate Impact and Feasibility Analysis of Incineration Based Waste-to-Energy Plants in Delhi

S.K. Singh, Adarsh Chawla*, Satvik Chhabra and Mahima
Department of Environmental Engineering, Delhi Technological University, New Delhi, India
✉ adarshchawla01@gmail.com

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Abstract: Managing the increasing municipal solid waste (MSW) generated in cities across India has increasingly become a challenge for Pollution Control Boards and Civic Authorities. The increasing population of Delhi has led to overflowing landfills that contaminate groundwater and release tonnes of greenhouse gases. Lately, waste to energy (WtE) plants have emerged as the preferred option in Delhi for waste processing but their adoption has been marred with public disapproval, emission violations and below-par energy production. This study quantifies the climate impact and investigates the financial feasibility of incineration based WtE units in Delhi. The Climate Impact estimates the Greenhouse Gas emissions of WtE Incinerators and compares them with the GHG emissions avoided via Electricity Generation and Landfilling. For Feasibility Analysis, the cost and revenue streams data were estimated to find out Net Present Values for the project lifecycle and Break-even Periods. The climate impact of all 3 WtE plants came out to be positive, with the Bawana WtE leading at 468,041 tonnes of CO_2-eq release. The Net Present Value after 20 years for Ghazipur, Bawana and Okhla WtE was at INR 594 million, 7541 million and 8965 million and break-even period was 12, 6, and 3 years, respectively. We conclude the study with policy recommendations & technical improvements aimed at improving feasibility, increasing renewable energy outputs and reducing the GHG emissions of WtE plants.

Keywords: Greenhouse gases; Climate change; Energy generation; Waste-to-energy; Landfill gases; Feasibility analysis.

Introduction

Developing countries produce waste at a rapid pace. Rapidly increasing urbanisation, economic development, and enhanced living standards are the main reasons that are quickly and rapidly driving waste production and are causing various socio-economic and environmental problems (Malinauskaite et al., 2017).

The world population has experienced tremendous growth in its population growth from 3.1 billion in 1960 to almost nearly 7 billion in 2010, and it is projected to rise to 9.3 billion by 2050 (FAO, 2013). This rapidly increasing population plays an important role in the production of a huge amount of municipal solid waste (MSW). The world generated 2.01 billion tonnes/year of waste in 2016, which is projected to reach 3.40 billion tonnes/year tons/year by 2050 (World Bank, 2018). A total of 1300 million tonnes/year of MSW is generated at a rate of 1.2 kg/capita/day (World Bank, 2012).

The cost of managing the rising MSW is expected to rise to a predicted $ 375 billion in 2025, which is almost double the cost of management calculated in 2010. These increasing costs will become an extremely critical issue for developing nations and those nations with less GDP. Developing countries like India mostly utilise Landfill Dumping on government-owned land

*Corresponding Author

which only incurs huge environmental degradation and maintenance costs without producing any revenue (World Bank, 2018). The upcoming technologies like the Waste-to-Energy technologies not only provide a clean way to manage the rising MSW but also provide a significant revenue stream and profit for those employing this solution. This ability makes them a popular choice for MSW management solutions in a country (Abdallah et al., 2018).

The National Capital Territory of Delhi (NCT) generates 11144 Tonnes Per Day (TPD) of MSW, which is managed across 5 urban local bodies. Out of the 11144 tonnes of MSW, 5249 tons, i.e 47% of MSW is processed and treated while the remaining 5885 tonnes of MSW is dumped into the 3 landfills of Delhi, that are Ghazipur, Okhla and Bhalswa (DPCC 2021). Municipal Compost Plants, Engineered Landfills, Decentralised Biomethanation Plants and Waste-To-Energy Plants consist of the waste processing facilities in the NCT of Delhi. The 3 landfills: Ghazipur, Bhalswa and Okhla occupy a total area of 152 acres and almost 4900 tonnes of MSW are dumped in these areas every day. This dumping of waste in landfills leads to almost 4000 Gigagram of CH_4 emissions every year leading to global warming and climate change and has an atmospheric residence time of 12-15 years (Singh, 2016).

A review of recent literature on the waste composition of dumped MSW across low, middle and high-income areas of Delhi reveals that over 70% of household waste generated and collected is biodegradable in nature, while illegally dumped waste is inert, on an average 60% in composition in non low income areas. While in low income areas, Household and dumped waste is always over 75% biodegradable in nature, which indicates a trend of low calorific values and high moisture in MSW (Nagpure, 2019). In terms of literature on Energy Recovery from MSW, Ghosh et al. (2019) conclude that methane recovery from landfills in 2015 would be enough to power 800,000 to 1,800,000 homes in Delhi by generating electricity at 100KWh of average annual electricity consumption per household.

One of the main objectives of the Central and State Government regarding Solid Waste Management in New Delhi is to close the gap between the MSW that is generated and treated in the city (CPCB 2016). Waste-to-Energy plants are among the top priorities of the Government to close this gap, and new incineration-based WtE units are being proposed and commissioned across New Delhi and other parts of India rapidly (DPCC, 2021; CPCB, 2016). As of 2022, there are three operational Waste-to-Energy plants in Delhi, all of them being incinerator based with a total design capacity to process 5450 tonnes of MSW every day and generate 59 MW of energy every hour at maximum capacity (DPCC, 2021). These Waste-to-Energy plants are located in Ghazipur, Okhla and Bawana (CPCB, 2021).

Due to a high amount of biodegradable and organic waste in the MSW in Delhi (45-50%), which is high in moisture (45%) and has very low segregation at the source, the resulting calorific values are around 1400-1600 cal/kg, which is much lower than the prescribed sustainable values of around 1800 cal/kg and above 2000 cal/kg to be profitable. Only 13% of Delhi's MSW was found to be above 3000 cal/kg (Bhusan et al., 2018). The lack of segregation and bulk incineration of waste also results in the emission of noxious gases which are extremely toxic to humans and affect the quality of life in a metropolitan hub like Delhi (Beychok, 1987). In addition to inferior quality waste, the WtE plants in New Delhi have been fined on multiple instances by the National Green Tribunal for flouting emission norms (NGT, 2021).

On the other hand, WtE plants prevent the emissions of greenhouse gases from landfills and also reduce CO_2 emissions from fossil fuel sources when electricity is generated. This study aims to find out if the GHG emissions released by these incinerators outweigh the GHG emissions avoided by them, and further find out the financial feasibility of operating these plants in Delhi, with a lower calorific value of MSW and high moisture content.

The results of this analysis will help the policymakers and citizens find out the climate impact and financial feasibility of operating a WtE plant in India and will help guide future decision-making.

Currently, the potential for MSW to be used as a renewable energy source has been discussed and analysed but quantification of the potential has not been carried out (Malav et al., 2020). For incineration-based Waste-to-Energy units, Feasibility Analysis has not been conducted as per published literature, despite the need for the same signalled by the rising MSW. Abushammala et al. (2021) discussed the Feasibility of Waste-to-Energy technologies in Oman as a whole, and this study takes a similar approach to quantify various parameters, however, the focus is on operational WtE plants instead of overall potential.

Methodology

This study aims to quantify the carbon impact and analyse the Financial Feasibility of the three currently functioning incinerator-based Waste-to-Energy Plants in Delhi. These plants are situated in Ghazipur, Okhla and Bawana. To assess the Climate Impact of these Waste-to-Energy units, this study will holistically look into the carbon saved and emitted directly and indirectly by them, by calculating the GHG emissions reduced by clean energy generation, CH_4 and CO_2 emissions from landfilling avoided and the greenhouse gas emitted during operation. The financial feasibility analysis will include the calculation of Revenue Streams from electricity and Carbon Credit sales, Capital and Operational Costs across the project lifecycle to find out the Break-even Period using a Net Present Value calculation.

Based on the results of this study, discussions and strategies for optimising the Municipal Solid Waste collection, segregation and processing for maximising the calorific value of MSW and energy output of these plants have been included. Figures 1 and 2 show a graphical representation of this study's methodology.

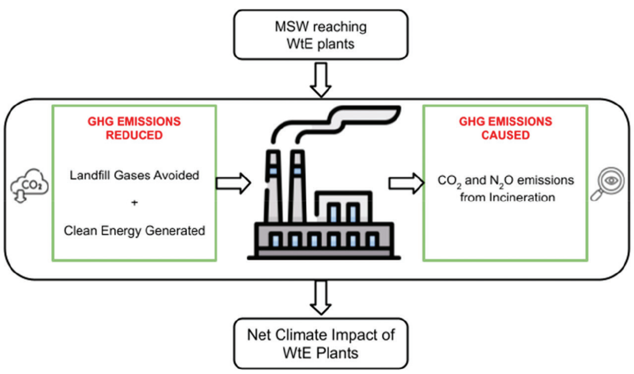

Figure 1: Climate impact.

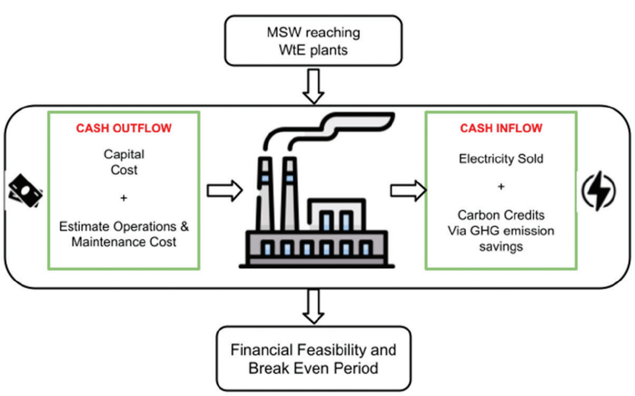

Figure 2: Financial feasibility.

Waste Composition

The composition of landfill waste is the deciding factor to calculate the methane and carbon dioxide emissions from a landfill and carbon dioxide emissions from various incinerators. Existing literature reveals the composition of Municipal Solid Waste in Delhi (TERI, 2002; NEERI, 1996) represented in Table 1, as well as the waste reaching various Landfills in Delhi as shown in Table 2 (MCD, 2004).

Table 1: Physical composition of MSW in Delhi

Physical Components	*2002 (% of weight in MSW)*	*1995 (% of weight in MSW)*
Biodegradable	38.6	38.0
Paper	5.6	5.6
Plastic	6.0	6.0
Metal	0.2	0.3
Glass & Crockery	1.0	1.0
Leather, Rubber, Synthetic	13.9	14.0
Inert (Stones, Brick, Ashes)	34.7	34.8

Source. (TERI, 2002), (NEERI, 1996)

Table 2: Composition of MSW reaching Delhi landfills

Component	*% by weight in Landfills*
Biodegradables (Kitchen waste, paper, textiles, leaves, green waste)	73.7
Recyclables (Metal, Plastic, Glass, Rubber)	9.2
Inert (Concrete, Sand, Bricks, Stone)	17.1
Others	6.3
Moisture	47

Source: (MCD, 2004)

Net Carbon Impact Calculations

The greenhouse gas emissions generated from the Waste-to-Energy Incinerators are compared with the greenhouse gas emissions reduced by avoiding landfilling and by generating Clean Energy every day. The Ghazipur, Okhla and Bhalswa landfills collectively receive more than 5000 tonnes per day of MSW and release more than 4000 Gg of methane per year (Singh et al., 2016). Methane has a global warming potential of 21 over a period of 100 years (IPCC,1995). When the waste is processed and incinerated in these Waste-to-Energy plants, they release carbon dioxide and N_2O in trace amounts and result in much lower GHG contribution to the environment (IPCC, 2006).

Landfill Gas Estimation

Landfill gas or gases emitted from waste landfills due to anaerobic decomposition of MSW contains 50%-55% methane (CH_4) and 45%-40% carbon dioxide (CO_2) along with other trace gases (Hegde et al., 2003). This study uses the IPCC (1996) default method to estimate the CH_4 emissions, and the EPA (2003) methodology to estimate CO_2 emissions that would be avoided annually by not dumping MSW into landfills and using incinerators instead.

$$CH_4\ (Gg/yr) = [MSW_T * MSW_F * MCF * DOC * DOC_F * F * (16/12 - R) * (1 - OX)] \quad (1)$$

where Gg = 1000 tonnes, $MSW_T * MSW_F$ is the annual waste intake of WtEs, MCF is the methane correction factor, DOC is degradable organic carbon value, DOC_F is the fraction of DOC dissimilated, F is the fraction of CH_4 in landfill gas, R is the CH_4 gas recovered and OX is the oxidation factor. According to IPCC (1996), default values for MCF, DOC_F, F, R and OX are 0.6, 0.77, 0.5, 0 and 0, respectively. DOC values are taken as 0.15 for Bawana and Ghazipur and 0.14 for Okhla (Chakraborty et al., 2011).

To calculate the CO_2 emissions, this study will use the (EPA, 2010) methodology:

$$CO_2\ (Gg/yr) = \{A * [(1-F/F) + OX] * 44/16\} \quad (2)$$

where A = CH_4 emissions generated, F = Fraction of CH_4 in Landfill Gas and OX is the soil oxidation fraction for CO_2. Default values of F and OX are 0.5 and 0, respectively, according to IPCC (1996) and EPA (2010).

Carbon Dioxide and Nitrous Oxide Estimation from WtE Incinerators

Using the IPCC Guidelines (2006) and the accompanying decision tree, this study calculates the estimated carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions from Waste-to-Energy incinerators in Delhi. According to the IPCC Good Practice Guidelines (2000), CO_2 is the primary climate relevant greenhouse gas released from these units, and among other trace gases, N_2O is prioritised due to its high global warming potential (GWP) of 310 and relatively high emission factor of 32 mg/kWh. Using the IPCC Mass Balance Method (IPCC, 2006), the CO_2 emission can be calculated by the equation

$$CO_2(Gg/yr) = MSW(Gg/yr) * \sum_j (WF_j * dm_j * CF_j * FCF_j * OF) * 44/12 \quad (3)$$

where MSW is the annual waste incinerated in the WtEs, j is each waste type, WF_j is the fraction of each waste type in the total MSW, dm_j is the dry matter content of each waste type, CF_j is the fraction of Carbon in the dry component j, FCF_j is the fossil carbon fraction and OF_j is the oxidation fraction of each component. IPCC (2006) default for OF is 1. Table 3 provides the input parameters. Since the emission of biomass without a fossil fuel component does not contribute to Climate Change and is climate neutral, only MSW components with a fossil carbon fraction have been considered for climate-relevant emissions. (IPCC, 2006: Johnke, 2002). Therefore, the composition of food waste and leaves is not relevant due to a fossil carbon fraction of 0 (IPCC, 2006). The fraction of MSW values have been estimated from ranges and values provided in existing literature like TERI (2002), Jha et al. (2008), MCD (2004), Rawat et al. (2014) & Sebastian et al. (2020), UNFCC (2006). dm_j, CF_j and FCF_j values are taken from IPCC (2006).

N_2O emissions are estimated based on the waste input to incinerators and can be calculated using IPCC (2006) guidelines as follows

$$N_2O\ (Gg/yr) = MSW * EF_{N_2O} * 10^{-6} \quad (4)$$

where MSW is annual MSW burned in Gg, EF_{N_2O} is the emission factor of N_2O for MSW. IPCC (2006) default for EF_{N_2O} is 0.5 for Bawana and 0.6 for Okhla and Ghazipur, due to continuous & batch type incineration, respectively (CPCB, 2021).

Estimation of Carbon Dioxide Saved via Electricity Generation

The 3rd aspect of the carbon impact of these WtE Incinerators is the tonnes of CO_2 emissions that are avoided due to the generation of green electricity from these units. According to the Central Electrical Authority- Installed Capacity Report (CEA, 2022), coal accounted for 2,03,900 MW of installed energy which is 51% of the total installed capacity. The methodology explained in CO_2 Baseline Database for the Indian Power Sector Report (CEA, 2018) has been used in this study to estimate the potentially avoided CO_2 emissions

$$CO_2\ (tonnes/yr) = P_{MWh} * E_{sf} * E_O \quad (5)$$

where $P_{MW/yr}$ is the annual power generated in MW and E_{sf} is the weighted specific emission factor in tonnes of CO_2/MWh and E_O is the average power output as a

Table 3: Composition of waste reaching the WtE incinerators

	Fraction of component in MSW incinerated (WF_j)			*Dry Matter Content (dm_j) (%)*	*Fraction of Carbon in dry matter (CF_j) (%)*	*Fraction of Fossil Carbon (FCF_j) (%)*
WtE Location	Ghazipur	Bawana	Okhla			
Rubber & Leather	1.16	1.83	0.75	84	67	20
Textiles & Rags	8.68	8	6.34	80	50	25
Plastic	5.24	4.17	5.6	100	75	100
Paper/ Cardboard	1.74	6.5	6.5	90	46	100
Inert Waste (Soil, Ash, Bricks, Stone)	29.63	36.56	36.56	90	5	100

percentage of peak output. Average efficiency or power output has been taken from CPCB (2021) compliance reports. The E_{sf} is taken as 0.82 according to CEA (2018).

Financial Feasibility

Costs

The cost of WtE Units has been divided into capital and operation costs. Capital Expenditure (CAPEX) includes the cost of construction, infrastructure and facilities while Operational Expenditure (OPEX) includes maintenance, salaries and refurbishing. The land acquisition cost has been excluded as these WtE Units are built on Public-Private Partnerships with Land Grants being a part of the Government Incentive (Ramky, 2010).

The CAPEX has been sourced from EIA Reports of the projects and Official Press Releases while the OPEX has been sourced from EIA reports where available and otherwise estimated to a similar percentage using the methods given by Gómez et al. (2010) and Alzate-Arias et al. (2018). Table 4 lists all the WtE design parameters used in the financial feasibility calculations.

Table 4: WtE parameters

Parameters	*Ghazipur*	*Bawana*	*Okhla*
CAPEX(in INR millions)	1342.8	4580	2040
OPEX (in INR crores)	97	320.6	142.8
Operating Hours/Yr	8760	8760	8760
Design Capacity (tonnes Per Day)	1300	2200	1950
Power Generation(MW/hr)	12	24	23
Self Consumption (***U***)	26%	15%	22%
Average Electricity Selling Price (Rs/unit)	5	7.03	7
Average Output (% of peak power)	25%	75%	70%

Source: (UNFCC,2006), (Ramky, 2010), (NGT, 2017), CPCB(2021) Personal Communication. OPEX has been estimated as 7% of CAPEX for Bawana WtE and Okhla WtE based on similar estimates in (UNFCC, 2006) and (Gómez et al., 2010; Alzate-Arias et al., 2018).

Revenue

Revenue streams can be broken down into 2 major categories for Waste-to-Energy Plants in Delhi. These would be revenue from the generated electricity that is sold to private and public bidders and the carbon credits revenue generated by preventing landfill gas emissions, fossil fuel electricity generation and subtracting the GHG emissions of each plant. The GHG emissions saved will be then converted into CO_2 equivalents and sold as Carbon Credits. The energy utilised by the WtE plants themselves will be subtracted from the total energy sold to the DISCOMS annually.

Based on the Energy Output of each WtE plant, Electricity Revenue can be calculated as

$$R_E = E_O (1 - U) * T_E * E_O \qquad (6)$$

where E_O is the electricity generated at each plant, U is the self-energy consumption, E_O is the average power output as % of peak power and T_E is the average electricity tariff. Values are given in the table above.

According to IPCC (1992), 1 Carbon Credit or Carbon Offset is defined as the allowance for the owner to use or sell 1 tonne of CO_2 or equivalent greenhouse gas. Based on emissions of WtE plants and their emission reductions, the Carbon Credits accrued are calculated as follows in equation 7.

$$\text{Carbon Credits} = (E_L + E_F) - E_{WTE} \qquad (7)$$

where E_L is the CO_2 equivalent of total landfill gas emissions, E_F is the CO_2 eq emissions saved from substituting electricity from Fossil Fuel sources, E_{WTE} is the CO_2 eq emissions generated from the WtE plant themselves (Abushammala, 2021). The average price in the voluntary carbon credit market is around $10 per Carbon Credit as of April 2022 (Abdallah et al., 2018).

Net Present Value (NPV) & Break-even Analysis

The NPV is an important metric in the feasibility assessment of any project. It is the balance of all cash inflow and outflow in a given time period. A positive NPV indicates that the project is profitable. The formula for NPV is

$$NPV = \sum_{t-1}^{n} (CI_t - CO_t)/(1+i)^t \quad (8)$$

where CI_t is cash inflow and CO_t is cash outflow in year (t), n is the project life and i is the discount rate (Zhao et al., 2015). Since the projects are funded in a PPP model, the discount rate can safely be taken as 5% as the government has given significant grants and corporate entities self-fund these projects (Abdallah et al., 2018). The break-even analysis will include the time periods for each of the projects to become profitable and be financially self-sustainable for the rest of their project lifecycles. When the sum of cash inflow over the project lifecycle becomes more than the cumulative sum of cash outflow, discount rate and CAPEX over the project lifecycle, the project is said to break-even, and the time taken to break-even is the break-even period.

Results and Discussion

The results will first include the Climate Impact calculations of these WtE plants. The emissions generated from WtE plants are compared against the Greenhouse Landfill gases saved and fossil fuel energy substituted to find out if the WtE plants are net Carbon Negative or Positive and to what extent. Further, the feasibility is discussed via the cost and revenue streams with Net Present Value and Break-even Period.

Landfill Gas Emissions and Electricity Emissions Avoided

The landfill gas calculations include methane (CH_4) and carbon dioxide(CO_2) that are released from waste landfills. They have been calculated using Equations (1) and (2). The annual values of CH_4 and CO_2 emissions avoided in tonnes/year and CO_2 eq are given in Table 5. The tonnes of carbon dioxide emissions avoided by substituting conventional electricity generation are also given below. Landfill gas avoided and CO_2 emissions from electricity generation avoided are compared with the emissions of the WTE plants to find out the net climate impact of these WtE plants. It is calculated that Bawana WtE Incinerator causes the maximum savings of landfill gases at 1020591.4 tonnes of CO_2 eq every year. Okhla incinerator is the 2nd highest with 852992.6 tonnes of CO_2 emissions avoided every year. All values are annual.

Table 5: GHG Emissions avoided from WtE incinerators

	Ghazipur	*Bawana*	*Okhla*
CH_4 (ton/yr)	21921.9	37098.6	30690.66
Methane emissions in CO_2-eq (ton/yr)	460359.9	779070.6	644503.86
CO_2 (ton/yr) (Landfill)	66313.75	112223.27	92839.25
Landfill gas total in CO_2-eq (ton/yr)	526673.6	891293.9	737343.1
CO2 emissions from electricity generation (ton/yr)	21549.6	129297.6	115649.52
Total emissions avoided in CO_2-eq (ton/yr)	548223.2	1020591.4	852992.6

Emissions from WtE Incinerators

The total CO_2 and N_2O emissions released from the 3 WtE incinerators have been calculated using Equations 3 & 4 given above based on the composition of the incoming waste at the 3 WtE facilities. The values for WtE emissions are given in Table 6. N_2O emissions have been converted into CO_2-eq values using a multiplier of 310 as per IPCC (1995). It is observed that due to the Bawana plant utilising a continuous incinerator, its N_2O emissions are lower than the Okhla plant despite

Table 6: GHG emissions caused by WtE incinerators

	Ghazipur WtE	*Bawana WtE*	*Okhla WtE*
CO_2 (tons/yr)	252959.2	428084.9	379438.9
N_2O emissions (tons/yr)	284.7	401.5	427.05
N_2O emissions in CO_2 eq (tons/yr)	88257	124465	132385.5
Total emissions	341216.2	552549.9	511824.4

having a much larger waste incineration capacity (2200 TPD), which is the result of a lower emission factor. Nonetheless, in terms of total emissions, Bawana WtE is the highest with 552549.9 tonnes of CO_2-eq emissions per year. All values are annual.

Net Emissions

The purpose of calculating all these emissions (as shown in Table 6) was to find out the net carbon impact of each of these WtE Plants. The landfill gas emissions avoided and CO_2 emissions reduced by substituting fossil fuel electricity are compared to the actual greenhouse gas emissions of these WtE plants, which comprise CO_2 and N_2O. The total positive emissions or emissions saved are represented by the landfill and electricity emissions saved while the WtE incinerator releasing greenhouse gases itself is taken on the negative emissions side.

The net resultant of positive and negative emissions are shown in the graphs below for each WtE plant. The waterfall graphs in Figures 3, 4 and 5 show the three streams of GHG emissions in a relative and absolute manner in tonnes of CO_2-eq so as to have a uniform unit of comparison. It can be inferred from the graphs that the majority of Greenhouse Gas emissions are avoided by not dumping the MSW into landfills. The GHG emissions reduced by electricity contribute less

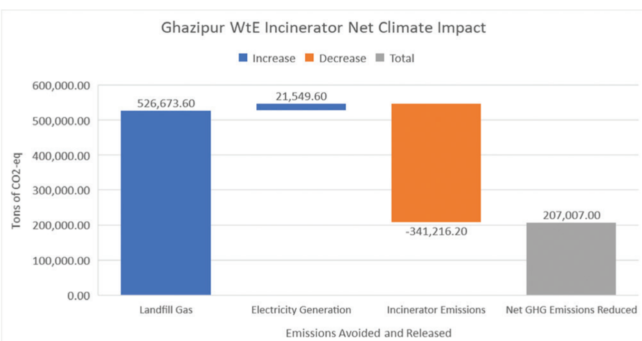

Figure 3: Ghazipur WtE net climate impact.

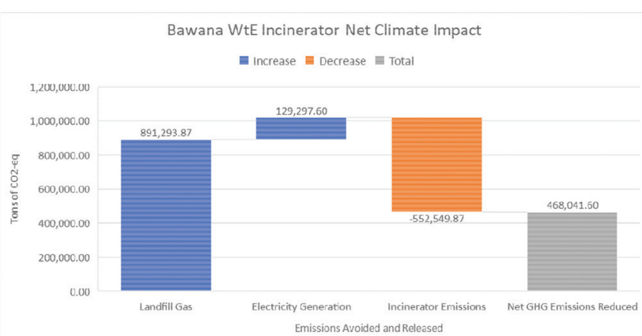

Figure 4: Bawana WtE net climate impact.

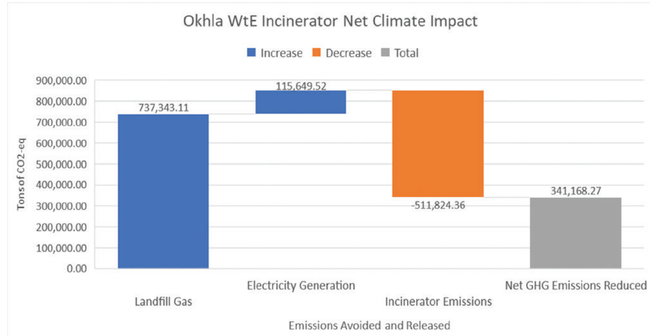

Figure 5: Okhla WtE net climate impact.

than 20% in all 3 cases due to the lesser efficiency of each of the WtE plants, especially the Ghazipur WtE. Bawana WtE leads with annual GHG savings of 468,041 tonnes CO_2-eq while Okhla WtE saves 341,168 tonnes CO_2-eq and Ghazipur WtE saves 207007 tonnes CO_2-eq every year.

Feasibility Analysis

The Feasibility Analysis in this study has been conducted in a parallel but customised method for Indian conditions as has been utilised in the study by Abdallah et al. (2018; Abushammala et al. (2021). The Net Present Values are estimated for the project lifecycle to find out the Payback or Break-even period (Abdallah et al., 2018). Cost and Revenue streams have also been estimated based on the methodology adopted in the study of Abushammala et al. (2021).

Within the feasibility analysis of these three WtE plants, their revenue streams have been calculated to compare with their Capital and Operational Costs. The Revenue streams consist of Electricity Units sold to private and state DISCOMS and Carbon Credits sold in the Voluntary market. The average price for Carbon Credits in the Voluntary market is taken as \$10 with the average exchange rate of \$1 = INR 75 as of March 2022 (World Bank, 2022).

Carbon Credits accumulated and the revenue generated from their sale in the voluntary market is given in Table 7.

Bawana WtE leads in annual carbon credits accrued and revenue from them due to a larger waste capacity and lesser GHG emissions due to continous incinerators and superior waste pre-processing before incineration. The annual revenue from the sale of electricity to private and state parties is given in Table 8.

Revenue from electricity sale and carbon credit sale combines to give the total revenue from each of the WtE plants. Bawana WtE leads with combined revenue

Table 7: Carbon credits accrued and revenue

	Ghazipur WtE	*Bawana WtE*	*Okhla WtE*
CO2 eq tonnes of emissions reduced	200707	468041.6	341168.27
Number of Carbon Credits accrued annually	200707	468041.6	341168.27
Annual revenue from the sale of Carbon Credits (in INR)	155255250	351031200	255876202.5

Table 8: Revenue from eectricity sale

	Ghazipur WtE	*Bawana WtE*	*Okhla WtE*
Peak Output in MWh	12	24	23
Self Consumption	26%	15%	22%
Efficiency	25%	75%	70%
Average Price/ Unit in INR	5	7.03	7
Annual Revenue in INR	97236000	942216840	770056560

of Rs 1,293,248,038.15. This is due to high efficiency in terms of electricity output, low self-consumption, highest peak output and a higher selling price per unit. These factors can be attributed to optimised operations, superior pre-processing of Refuse Derived Fuel, and use of continuous boilers which also result in lesser total emissions and a higher price for clean energy generated. Ghazipur WtE loses out on revenue majorly due to a lesser efficiency which was inferred and calculated from the compliance reports (CPCB 2021).

The graphs for annual net present values for each of the 3 WtE plants are given in Figures 6, 7 and 8. Figure 9 shows the comparison of break-even period or payback period when the cumulative NPV graph crosses the line of zero (Abushamala, 2021), for each of the 3 Incinerators. It comes out as 12, 6 and 3 years for Ghazipur, Bawana and Okhla, respectively.

The output of Financial Parameters for each of the three WtE plants is given in Table 9.

Conclusion

This study shows that even though Incineration based Waste-to-Energy plants can be an expensive way to

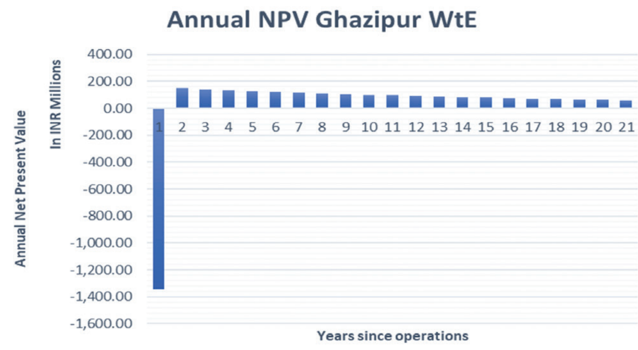

Figure 6: Annual NPV Ghazipur WtE.

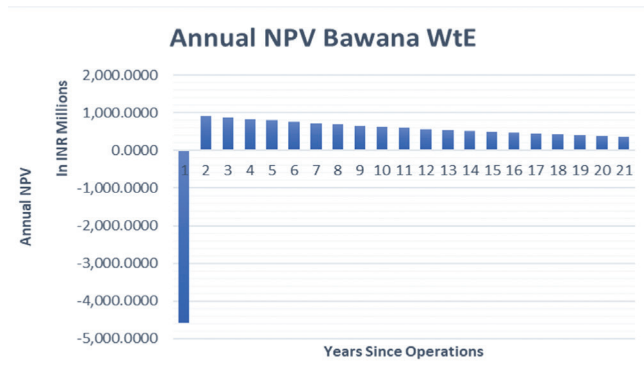

Figure 7: Annual NPV Bawana WtE.

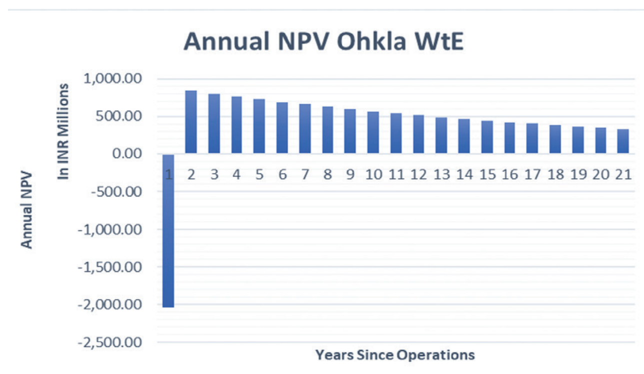

Figure 8: Annual NPV Okhla WtE.

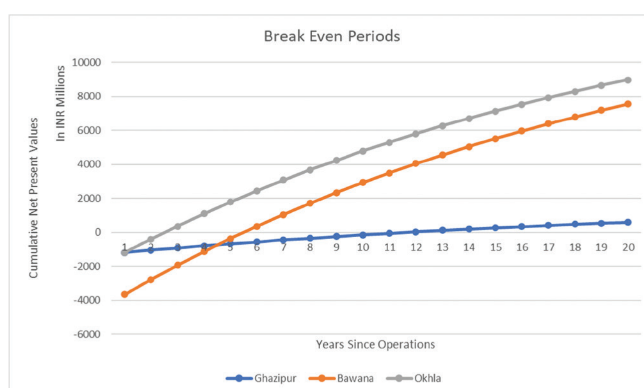

Figure 9: Comparison of break-even periods.

Table 9: Output of financial parameters

Parameters	*Ghazipur WtE*	*Bawana WtE*	*Okhla WtE*
NPV (20 yrs)(in INR)	594,964,663.9	7,541,344,440.68	8,965,786,246.66
Payback Period (Break-even) (in Years)	12	6	3

manage MSW due to high upfront costs and high greenhouse emissions when it comes to a net climate impact and feasibility study, they are extremely beneficial in terms of reducing Greenhouse Gas emissions and also being profitable in the long run. The tonnes of CO_2-eq GHG gases reduced falls between 200,000 and 468,000 tonnes per year when the Landfill Gas emissions and Electricity Generation are factored, subtracting their emissions. In terms of Financial Feasibility and profitability, it is observed that with more than 50% efficiency, these incinerators can break even in less than eight years and with 75% efficiency, they become profitable within 5 years, which is a great investment in the long run with a discount rate of 5%. Even with higher discount rates of 10%, profitability can be achieved within ten years.

An aspect that could not be included in this study is the emission of many other pollutants like particulate matter, SO_x and NO_x, and dioxins and furans from WtE plants (CPCB, 2021). Though the GHG emissions are a net negative, these toxic gases cause extreme negative health effects in the long term and degrade the quality of life. Further studies should also weigh in on these gases. But these emissions can be avoided by superior air purification systems installed in these incinerators.

Another issue plaguing these WtE plants that leads to lower profits and energy output is the high moisture content and low organic content in the MSW of Delhi. This leads to a low calorific value of the waste. This issue is aggravated by the absence of segregation at the source in the collection of MSW in Delhi, and more investment is needed to segregate the waste at the Incinerators.

This study only looks at Incineration based WtE plants as these are only functional WtE plants as of date, but further research must look into the feasibility of Gasification and Anaerobic Digestion techniques. A possible reason for less government and private investment into gasification and anaerobic digestion-based WtE plants is due to their much smaller capacities and waste treatment period, as biological decomposition of waste tends to be much slower. But a redeeming quality of these methods is the much lower capital investment and almost 0 greenhouse gas emissions. The MSW strategy should include the promotion of gasification and digestion WtE plants. Segregation at source should be implemented at the municipal level to make the Waste Management process more cost and energy efficient.

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