





Waste to Energy

What has been the impact of Waste-to-Energy plants projects done in Indian Smart Cities?

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Smart City

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FOREWORD

The mounting challenges of solid waste management in Indian cities demand more than just technological solutions, they call for systems thinking, participatory planning, and a deep understanding of the social, economic, and environmental contexts in which interventions unfold. Waste-to-Energy (WTE) has often been framed as a panacea in urban waste discourse, but its actual implementation has exposed significant complexities and contradictions.

This impact assessment study was conceived to unpack those complexities. By evaluating WTE projects in Indore, Ujjain, and Jabalpur, each adopting different technologies and governance models, we sought to examine not only the technical and financial performance of these interventions but also their environmental trade-offs, social inclusiveness, and institutional dynamics.

Our findings point to a need for caution and context-sensitivity in scaling WTE technologies. While bio-methanation models show promise, their success hinges on robust systems of source segregation, decentralized infrastructure, and community participation. The study also raises broader questions about the governance frameworks and institutional arrangements that underpin such interventions, particularly the need for clearly defined roles, responsibilities, and continuity mechanisms to ensure long-term sustainability.

As the Principal Investigator of this study, I am grateful to the Ministry of Housing and Urban Affairs for their support, to our research team for their dedication, to my co-author Rakendu for her leadership, and to the city-level stakeholders who shared their experiences with honesty and insight. I hope this report contributes to more informed, equitable, and environmentally just decisions in the evolving landscape of urban waste management in India.



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Executive Summary

Waste-to-Energy (WTE) conversions are considered critical for transitioning to a circular economy. Among the WTE technologies, incineration and bio-methanation are the most common, while gasification and pyrolysis remain unfeasible in the Indian context. However, WTE projects in India have shown a mixed success rate, facing implementation challenges. It is therefore crucial to conduct a comprehensive analysis of WTE plants considering environmental, economic and socio-institutional dimensions. This study evaluates the environmental, economic, and social impacts of three prominent WTE interventions implemented under the Smart City Mission (SCM) in Madhya Pradesh: Jabalpur (mass incineration plant (600 TPD)), Indore (Bio-CNG plant (550 TPD)), and Ujjain (decentralized bio-methanation plant (5 TPD)). The analysis aims to identify the scope and challenges in implementing WTE technologies in other cities. The study does assessments at two levels- at the national level, the response received on question bank from cities are used to evaluate the WTE status while at the city level, a case study approach is adopted, involving field visits, stakeholder interviews, and focus group discussions to gain in-depth insights into the scope and challenges of WTE projects.

Of all smart cities participated in secondary questionnaire (94 cities), 15 cities have implemented WTE plants. Nine cities including Indore, Ujjain, and Surat have implemented decentralized bio-methanation facilities while four cities (Jabalpur, Salem, Shillong, Vadodara) have implemented incineration plants and another four (Vadodara, Shimla, Rajkot, Jaipur) generate Refuse Derived Fuel (RDF) for co-processing in incinerators, cement or thermal power plants. The bio-methanation plants align well with Indian municipal solid waste (MSW) characteristics, which consist of 40–60% organic content, making them more suitable than incineration. However, a critical barrier identified for the implementation of any WTE technology is the lack of source segregation. 47% of cities have documented data on segregation rates, with 20 cities achieving over 80% segregation at source. This gap poses a substantial challenge to the effective operation of any WTE technology, that depend heavily on receiving high-quality feedstock. Moreover, it is important to conduct regular waste audits in cities to assess waste composition, which varies seasonally and across administrative boundaries, affecting the functioning of the plants. The financial allocations under the Smart City Mission currently shows a predominant focus on waste collection and transportation infrastructure, accounting for 63% of the total budget, while only 8% allocated to waste treatment infrastructure, highlighting a need for re-prioritization in the future. Comparing the three interventions revealed the following key insights across the three pillars of environmental, economic and social sustainability.

Environmental aspects: The bio-methanation plants are found to be more environment and climate friendly, provided they are well-maintained with minimal methane leakages. By diverting waste off the landfills and generating electricity or Bio CNG, it demonstrated significant GHG emission reductions (around 1.1 ton CO_2 eq. per ton of waste). While incineration reduces open dumping and

recovers energy, its direct emissions are found to be high and there are challenges with air quality due to particulate matter often exceeding permissible limits.

Economic aspects: The Indore Bio-CNG plant shows the potential of centralized bio-methanation facilities to attain economies of scale despite high Capex and Opex, with an annual revenue of around ₹ 53 crores and a positive net present value (NPV) of ₹ 88 crores. Decentralized models like Ujjain face financial viability issues due to low revenue generation (₹0.033 crores) and a negative NPV (₹-1.62 crore). However, these models offer significant indirect benefits, including reduced transportation costs and tipping fees. When such indirect savings are accounted for, and with sustained operations over a longer period, decentralized facilities have the potential to recover costs and enhance viability. In contrast, the incineration plant in Jabalpur, despite higher revenue generation of ₹60 crore, has undergone financial problems due to exorbitant operational and maintenance costs. These costs are further increased by the lack of quality feedstock within the city, necessitating its procurement from distant locations. This issue reflects a broader pattern of failure among incineration plants in India, primarily due to the composition of MSW, which is predominantly organic with low calorific value and high moisture content. Further, the tipping fee model incentivizes the quantity of waste disposal rather than its quality, resulting in significant quantities of inert waste entering the plants, which hampers operational efficiency and financial sustainability. To address these challenges, a cluster-based and integrated approach for WTE facilities is essential. Only high-calorific, non-recyclable, and combustible waste should be directed to incineration plants, while sustainable technologies like composting and bio-methanation should be prioritized for wet waste treatment. Source segregation must be actively promoted to ensure that waste is directed to appropriate processing streams, reducing dependency on standalone facilities and enhancing the efficacy of integrated waste management systems.

Social aspects: Decentralized models, like Ujjain's bio-methanation plant, are more found to be more inclusive and equitable as they do not shift the environmental burden to peripheral areas. These models facilitate community stewardship and awareness, promoting active community participation in waste management. The Indore model, while exhibiting the inherent disadvantage of a centralized facility, where nearby communities face issues of odour and flies, has shown significant improvement compared to earlier conditions. The site which was previously a trenching yard, has been reclaimed and transformed into urban forest plantations with better ecosystem services, along with WTE facilities, and recycling centres. Also, the integration of the informal waste sector has been a key feature of Indore SWM system, ensuring livelihoods and inclusivity. In Indore, the key success factor is the high-quality waste segregation at source into six types reflecting community participation. Further, the supporting infrastructure like Garbage Transfer Stations, dedicated vehicles and an optimized route plan has enabled effective waste management, with good-quality feedstock reaching

the facilities. In contrast, the Jabalpur model requires substantial improvement. The lack of source segregation undermines the effectiveness of the WTE facility. Without promoting segregation behaviour, transitioning to sustainable technologies in the future will be challenging for the city. Furthermore, the exclusion of informal waste workers from the formal system remains a critical issue. It is important to integrate or rehabilitate informal waste workers, address their needs, and resolve resource conflicts. Strengthening these aspects is essential to create socially and environmentally equitable SWM systems.

Governance and institutional aspects: play a critical role in the success of WTE projects and broader MSWM systems. There is a major need of collaborative governance among different stakeholders, often hindered by institutional fragmentation, overlapping roles, and undefined responsibilities, conflicts over ownerships were evident across the case studies. In Ujjain, following the tenure of the SCM, handing over projects to ULBs has faced hurdles, as the ULB lacks the financial capacity to manage ongoing operations and maintenance of the facility. The case of Ujjain's plant highlights the importance of involving all stakeholders during the decision-making phase, facilitating a participatory planning to bridge the silos between institutions. Integrated governance structures, involving missions, ULBs, state government departments, private entities, civil society organizations, and academia, should be established to facilitate regular dialogue and participatory planning.

Centralized, capital intensive projects often carry the risk of lock-ins, limiting flexibility and adaptability to evolving waste compositions or alternative sustainable technologies. It also hinders inclusive privatization as such projects only attract large private players, sidelining smaller agencies. To strengthen the sector, government subsidies and support are necessary to enable the participation of smaller private players, bringing context specific innovations and small-scale technologies that facilitate sustainable solutions. To ensure that private sector participation contributes positively to waste management, clear frameworks must be established to align profitability with sustainability goals. This involves mandating source segregation, ensuring transparency in environmental compliance, and enhancing the livelihoods of informal waste workers and sanitation workers. The approach to WTE projects should balance economic viability with environmental integrity and social equity, creating a system where private profits do not come at the expense of public goods. A more holistic approach is required to ensure that MSWM projects contribute effectively to sustainable urban development. This involves integrating external benefits into economic evaluations and balancing financial considerations with social, environmental, and economic impacts to select context-specific interventions that align with long-term sustainability goals.

Keywords: Waste-to-Energy, Circular Economy, Municipal Solid Waste, Source Segregation, mass incineration, Bio-CNG Plant, Decentralized Bio-Methanation, Environmental Sustainability, Social Equity, Governance Challenges, Techno-Economic Viability.

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List of Abbreviations

CE	Circular Economy
CNG	Compressed Natural Gas
ETP	Effluent Treatment Plant
GHG	Green House Gas
GTS	Garbage Transfer Station
IEISL	Indo Enviro Integrated Solutions Ltd
IMC	Indore Municipal Corporation
JMC	Jabalpur Municipal Corporation
LULC	Land Use Land Cover
MoEFCC	Ministry of Environment Forest and Climate Change
MoHUA	Ministry of Housing and Urban affairs
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
OMSW	Organic Municipal Solid Waste
PPP	Public Private Partnership
SCM	Smart Cities Mission
SPV	Special Purpose Vehicle
SWM	Solid Waste Management
TPD	Tones per day
ULB	Urban Local Body
UMC	Ujjain Municipal Corporation
WTE	Waste to Energy

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1. Introduction

1.1 Background

Solid Waste Management (SWM) pose a significant challenge in India, a country experiencing rapid urbanization[1], changing lifestyle and consumption patterns (Kumar & Agrawal, 2020). As per state of India's environment report, India is currently generating 1.5 lakh tones of Municipal Solid Waste (MSW) per day (CSE, 2023). It is increasing 5% every year and as per Ministry of Environment Forest and Climate Change (MoEFCC, 2016), MSW generation is expected to reach 4.5 lakh tones per day (TPD) by 2031. The existing practice of MSWM is found mostly linear that rely on a take make use dispose system (See Figure 1). In India 77% of MSW goes to unscientific landfills or open dumps (Kaza et al., 2018). Approximately, 80 to 90% of MSW disposed of in dump yards is subjected to open burning, thereby polluting the environment (Ahluwalia & Patel, 2018). This linear practice has adverse public health, environment and socio-economic implications (See Figure 2).

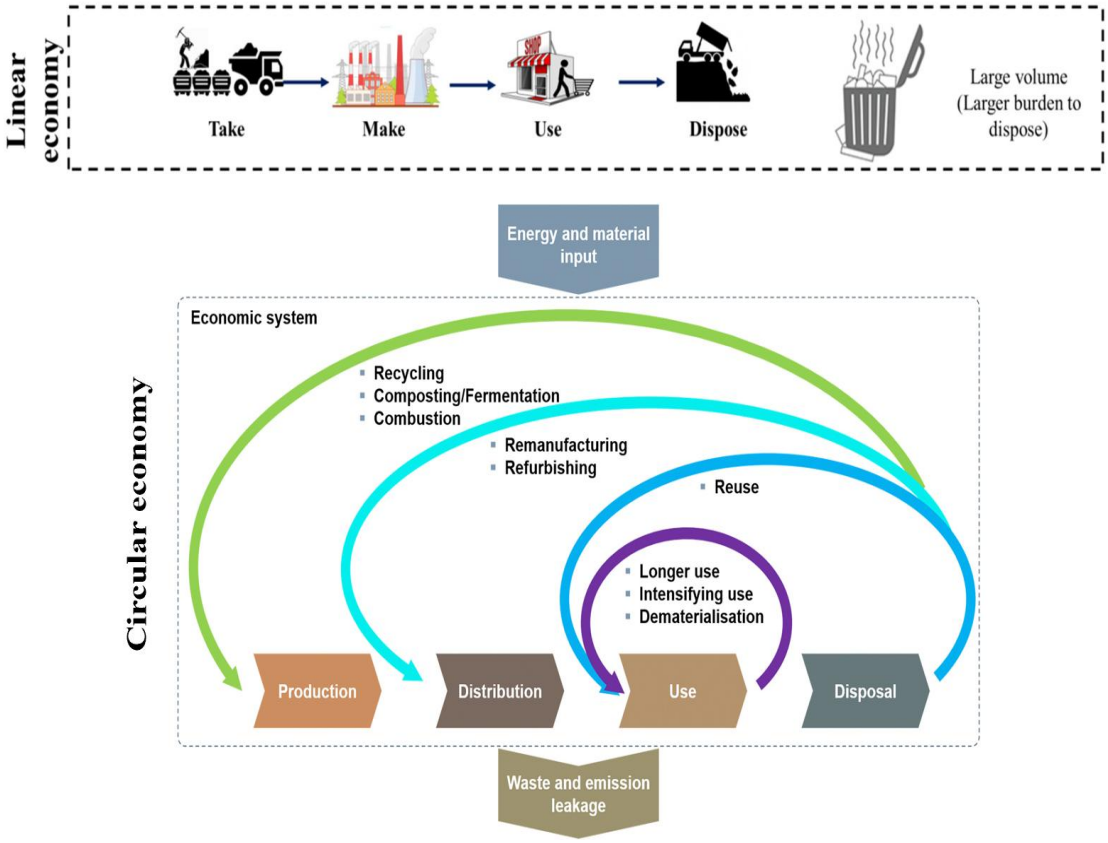


Figure 1: Linear Vs Circular Economy
Source: Geissdoerfer et al., 2020

[1] According to the 2011 census (Census of India, 2011), 31.2% of the population in India lives in urban areas, and it is projected to reach 50% by 2050 (United Nations Department of Social and Economic Affairs, 2018).

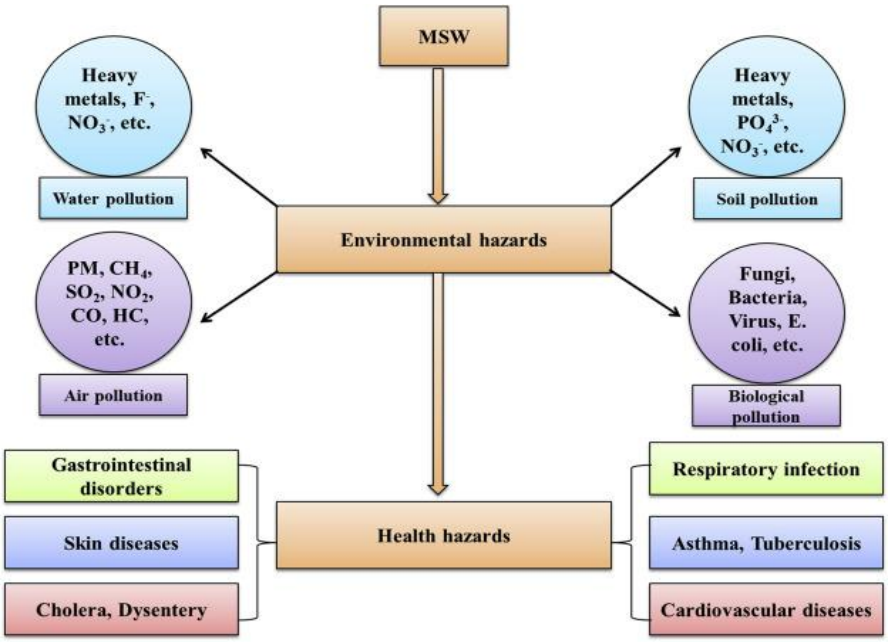


Figure 2: Impacts of improper MSWM
Source: Malav et al., 2020

In this context, the way ahead widely calls for a systemic shift (Hobson & Lynch, 2016) in conventional 'linear' waste management practices to a circular economy (CE) model based on Waste Hierarchy (Figure 3) (Sharma et al., 2021). CE transition is not only said to improve waste management, also contributes to mitigating the environmental impacts associated with improper waste disposal and creates employment opportunities in the sector, 'green jobs' (Stahel, 2016). It is important to note that waste hierarchy prioritizes waste management strategies from most to least environmentally friendly: prevention (reduce waste generation), reuse (extend the life of products), and recycling (convert waste into new materials). Energy recovery (converting waste to energy) and disposal (landfill/incineration without energy recovery) are the least preferred options (Van Ewijk & Stegemann, 2016). This implies that longer CE loops like Waste to Energy interventions should not be at the cost of shorter loops like reduce, reuse and recycling.

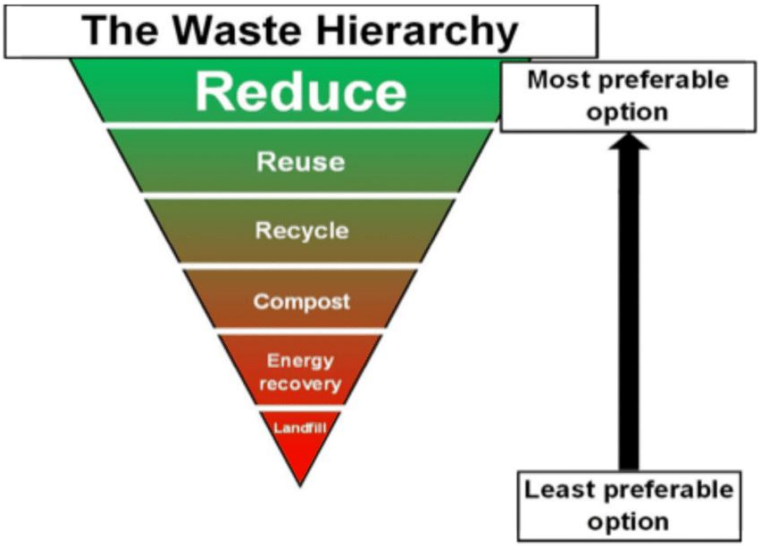


Figure 3: Waste Hierarchy
Source: Dong et al., 2021

There exist different technologies for converting waste to energy (WTE) (See Figure 4). However, in India, more than 80% of the WTE interventions (in terms of capacity) have been mass incineration-based (Swachh Survekshan, 2023), and only in recent years have alternative technologies like bio methanation started being widely implemented. The mass incineration based WTE has attracted a lot of criticisms in the Indian context when more than half of the implemented plants failed to operate (7 plants of 66 MW capacity failed out of 14 plants of 132 MW capacity during the period 1987-2019) (Sambyal & Agarwal, 2019). The reasons are attributed to the organic fraction of MSW (40-70%) with low calorific value and high moisture content and unsegregated nature of MSW, making it energy-intensive (Sambyal & Agarwal, 2019; CFA, 2022; Luthra, 2018; UNEP, 2019). The technology is also critiqued for its adverse impact on the environment and public health, economic infeasibility and exclusion of informal waste pickers (Ibid). While concerns are raised about incineration-based technology, there is limited research on the impacts of bio methanation based WTE plants. It is therefore crucial to conduct a comprehensive scientific analysis of WTE plants considering environmental, economic, and social dimensions. Such an analysis is vital for policymakers to make informed decisions about the adoption of WTE technology, determining its technology, suitability and scale. By evaluating the impacts, policymakers can contribute to sustainable waste management strategies that align with India's unique waste composition and challenges. Setting this as the context, this study assesses the impact of the waste-to-energy interventions implemented under the Smart Cities Mission (SCM), one of the solutions prescribed by the Ministry of Housing and Urban Affairs (MoHUA) to address the escalating solid waste crisis in the country.

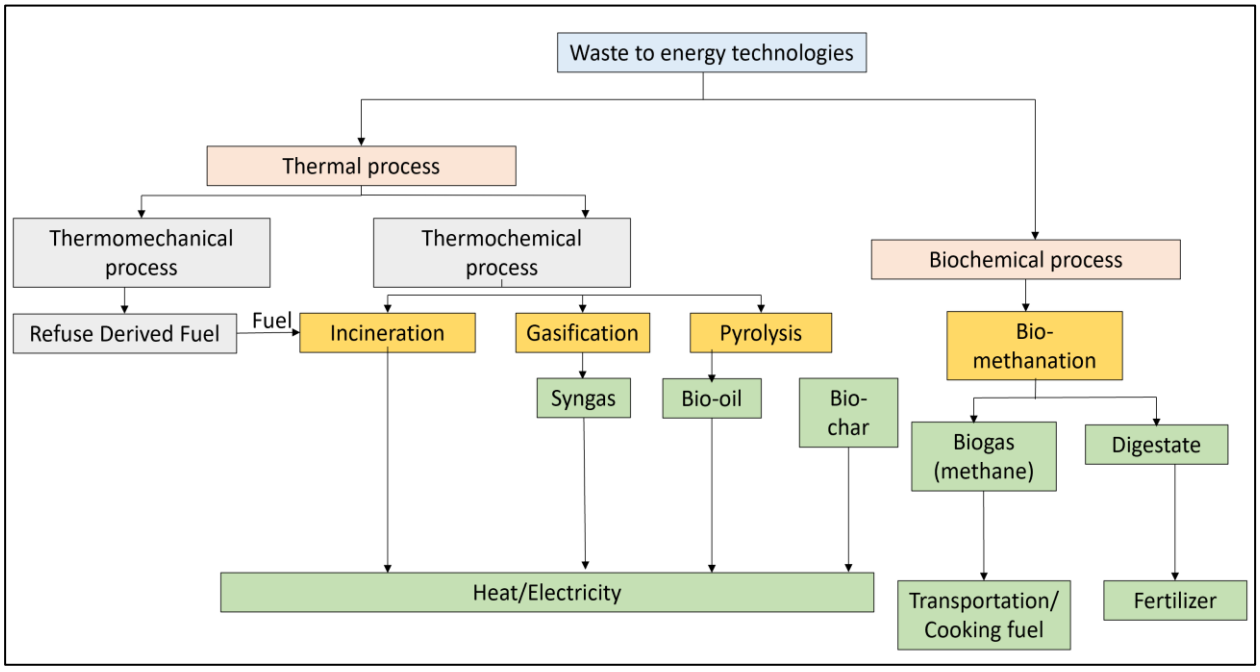


Figure 4: Waste to energy technologies

1.2 Objectives

i) To assess the environmental, economic and social impacts of WTE interventions under the Smart Cities Mission (SCM)

ii) To identify scope and challenges in implementing WTE technologies for effective replicability and scalability in other smart cities

1.3 Scope of the research

According to MoHUA, three smart cities in the state of Madhya Pradesh have pioneered the implementation of waste to energy plants under smart city mission: Indore, Jabalpur and Ujjain. The three cities have adopted three different technologies of different capacities/scales (See Table 1). While Jabalpur has adopted conventional mass incineration-based technology that would treat unsegregated mixed waste, the Indore city has adopted a Bio CNG plant to treat the segregated wet waste produced in the city. While both these cities have adopted a large-scale centralized facility, the third city, Ujjain has adopted a small-scale decentralized plant to treat the wet waste produced in the nearby market area and restaurants.

Assessing the impacts of these three differently scaled WTE technologies will clarify their effectiveness and suitability for addressing city-specific solid waste management challenges. This evaluation can guide policymakers in replicating and scaling these technologies in other urban contexts, identify key challenges, and highlighting areas for improvement, thereby promoting more sustainable waste management strategies under the Smart Cities Mission.

Table 1: Smart cities selected for case study

Smart city	WTE technology	Capacity
Indore	Bio- CNG (Waste to biogas to compressed natural gas)	550 TPD
Ujjain	Bio methanation (waste to Biogas to electricity)	5 TPD
Jabalpur	Mass incineration (Waste to electricity)	600 TPD

1.4 Limitations of the research

i) While studying different WTE technologies of different scales helps to diversify knowledge and has good advantages in terms of broad applicability and scalability, the lack of comparison of the same scale technology working in two different contexts can be a limitation in terms of drawing context specific factors that influence the outcomes.

ii) The study considers factors and indicators that define the broader pillars of economic, environmental, and social sustainability, applicable across all WTE systems. It does not delve into specific performance indicators of WTE systems (e.g., organic waste stabilization efficiency), which are often technology-specific and not the primary focus or purpose of this work.

iii) Variations in data quality and availability from different cities posed challenges for uniform assessment.

2. Methodology

2.1 National level assessment

The national-level assessment of waste-to-energy (WTE) plants under the Smart City Mission (SCM) was part of a broader evaluation spanning 50 thematic areas, including Theme 24: Waste-to-Energy. A standardized question bank was disseminated to nodal officers of all 100 Smart Cities to ensure uniformity in data collection and reporting. This question bank included specific parameters relevant to WTE plants: number of plants, their total cost in crores, and the solid waste processing capacity in tonnes per day (TPD), energy generation capacity, involvement of private entities, date of operationalisation, type of technology etc. To understand the upstream, and downstream linkages that affects the functioning of WTE plants, the questionnaire also inquired about the percentage of households covered by door-to-door waste collection and those segregating waste at the source. Additionally, it explored the city's waste composition, breaking it down into categories such as organic waste, plastics, paper, metal, and glass, while also seeking details on the total quantity of waste treated, recycled, or landfilled. Financial aspects were addressed through queries on the cost of electricity or biogas generated. Out of the 100 smart cities, 95 provided responses, which were analysed to assess the implementation of waste-to-energy plants, focusing on their integration into urban waste management systems and their role to sustainable waste processing goals.

2.2 Conceptual Framework for city level assessment

The impact assessment study considers indicators from three pillars of sustainability: environmental, economic and social and adopts a life cycle approach considering a series of processes from door-to-door collection, transportation, waste to energy conversion, forward linkages of outputs and disposal of the residues. The system boundary considered for impact assessment is shown in Figure 5. The framework of indicators used for sustainability assessment of WTE plants are given in Figure 6.

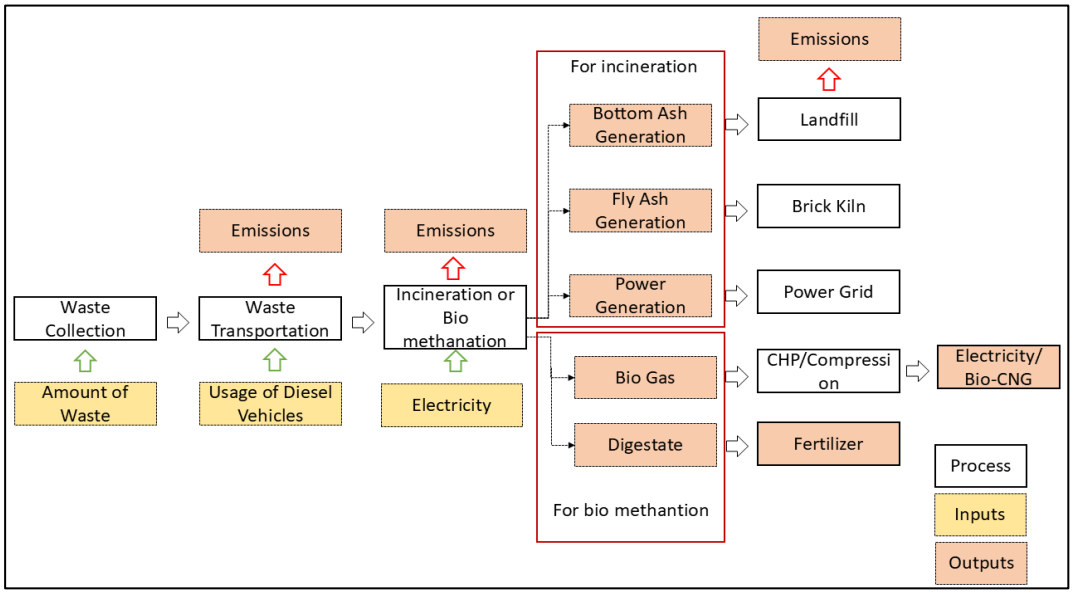


Figure 5: System boundary considered for impact assessment study

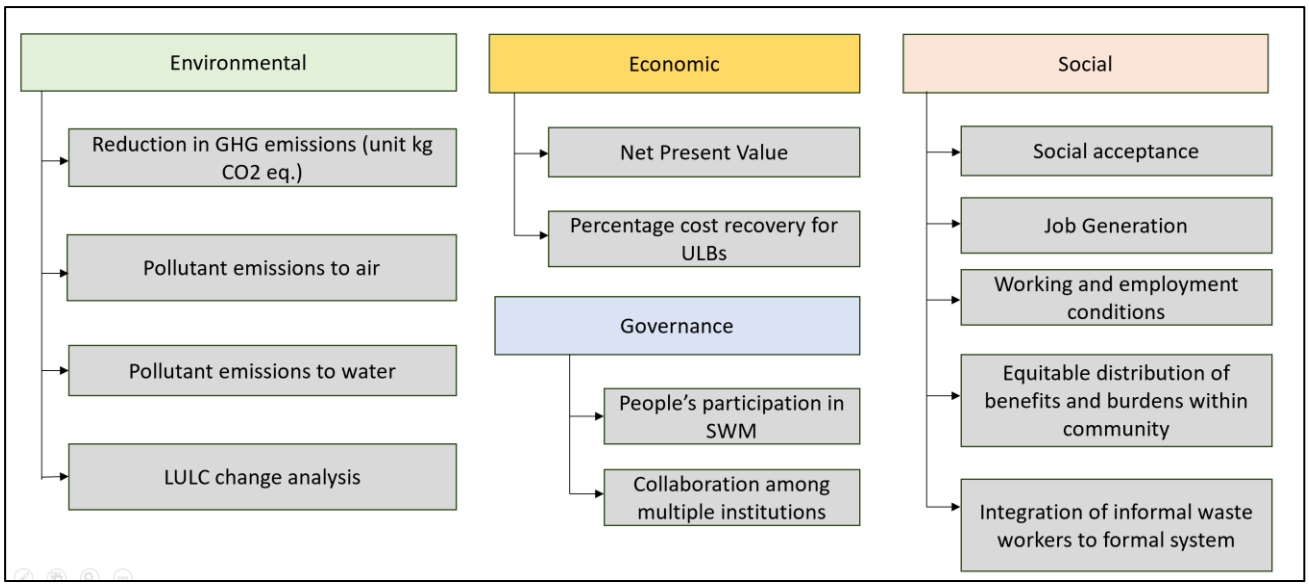


Figure 6: Indicators for sustainability assessment of WTE plants

Environmental sustainability

The main indicator used for environmental sustainability assessment is the reduction in GHG emissions (measured in kg CO_2 eq.), which quantifies climate change mitigation through WTE interventions. These include (i) replacing fossil fuels (coal-based diesel or power) with electricity or Bio-CNG production, (ii) diverting municipal solid waste (MSW) from landfilling, (iii) replacing chemical fertilizers with fertilizers produced from the slurry of anaerobic digestion in bio-methanation processes, (iv) reducing transportation emissions in the case of decentralized facilities, and (v) reutilizing fly ash in incineration plants. Direct emissions during the WTE conversion process are also calculated, along with embodied emissions from waste transportation and electricity consumption at the plant. Wherever site-specific data was available, it was used; in its absence, IPCC default values from the Greenhouse Gas Inventory (2019) and methods from IPCC (2006, 2019) were applied for emission calculations.

For assessing the impact on air pollution, particularly in incineration plants, a technology often critiqued for emitting pollutants, stack emission data for particulate matter (PM), SO_2, and NO_2 was analysed. To understand the impacts on nearby water bodies, pollution levels in the nearby borewells of the centralized WTE plants were assessed (as per the data availability in India WRIS portal) using weighted average water quality index calculation method. To evaluate the recovery of land resources from dump yards, land use land cover (LULC) change analysis was conducted for centralized waste-to-energy facilities. This analysis assessed reductions in landfill area and alterations in land use patterns resulting from the plant's operations, offering insights into the environmental and spatial impacts of WTE interventions. The methodology for LULC analysis is attached in Appendix 4.

Economic sustainability

The economic sustainability implies that the WTE system secures sufficient revenues to ensure an economically sound and continuous operation over a period of analysis (Chong et al., 2016). It is underpinned by the cost and revenue components of the WTE system. It also considers the financial model in which the urban local body or smart city mission funds or generates revenue from the plant. A life cycle cost analysis using present worth method was done to understand the economic viability. The cost recovery to municipality in SWM due to the functioning of WTE plant was another major indicator considered for assessing the economic sustainability. This is particularly important in the context of India, where ULBs often struggle with limited financial resources to manage SWM effectively, making cost recovery mechanisms essential for ensuring the long-term viability of waste management systems.

Socio-institutional sustainability

The indicators considered for socio-institutional sustainability assessment is given in Table 2.

Table 2: Indicators for socio-institutional sustainability

Indicators	Description
Social acceptance	Public health concerns such as odour, flies, or poor air quality often lead to opposition and protests, which can affect the long-term functioning and acceptability of the plant. This opposition can also be sometimes driven by the "Not In My Backyard" (NIMBY) phenomenon, where communities support the idea of sustainable waste management but resist having such facilities located near their residences due to perceived environmental and health risks. Addressing these concerns through transparent communication and community engagement is crucial for enhancing social acceptance.
Job generation	The plant's potential to generate local employment opportunities, contributing to the socio-economic upliftment of the surrounding community.
Working and employment conditions	Ensuring safe and better working conditions for workers in the SWM chain from collection to treatment to disposal, adhering to labor laws and occupational safety standards.
Equitable distribution of benefits & burdens within community	Ensuring that the benefits of the plant, such as improved SWM services, are shared equitably across the community while the environmental and social burdens, such as odor or pollution, are not disproportionately borne by those living in close proximity to the plant.
Integration of informal waste workers to formal system	Informal waste workers are often excluded from formal solid waste management (SWM) systems, which deprives them of their livelihoods as they lose access to waste materials that form the basis of their income. Their integration into the formal system is essential to ensure social equity, provide stable employment opportunities, and recognize their contributions to sustainable waste management practices.

Indicators	Description
People's participation in solid waste management	People's participation is a crucial aspect determining the long-term sustainability of solid waste governance. It includes their participation in both SWM practices (like source segregation) as well as in decision making (like resource allocation).
Collaboration among multiple institutions	Institutional fragmentation is a major challenge in urban governance in India, often marked by a lack of clear guidelines, overlapping roles and responsibilities and conflicts among multiple institutions. Effective collaboration among institutions is critical for long term sustenance of SWM systems.

2.3 Data collection and analysis methods

A case study method is used to study the impacts of WTE technologies under the smart city mission. Three pioneering smart cities that have implemented WTE based on different technology and scale were selected: Indore, Ujjain and Jabalpur (See Figure 7 and Table 1). The city of Indore has implemented Asia's largest Bio methanation plant (550 TPD) that generates Compressed Natural Gas (CNG) which is used to run the city buses. The city of Jabalpur has implemented a mass incineration-based plant (600 TPD) that treats mixed waste and Ujjain has implemented a 5TPD small scale decentralized bio methanation plant that generates electricity from market and restaurants. This would provide unique insights into the scope and challenges of replicating these technologies in different scales into other smart cities.

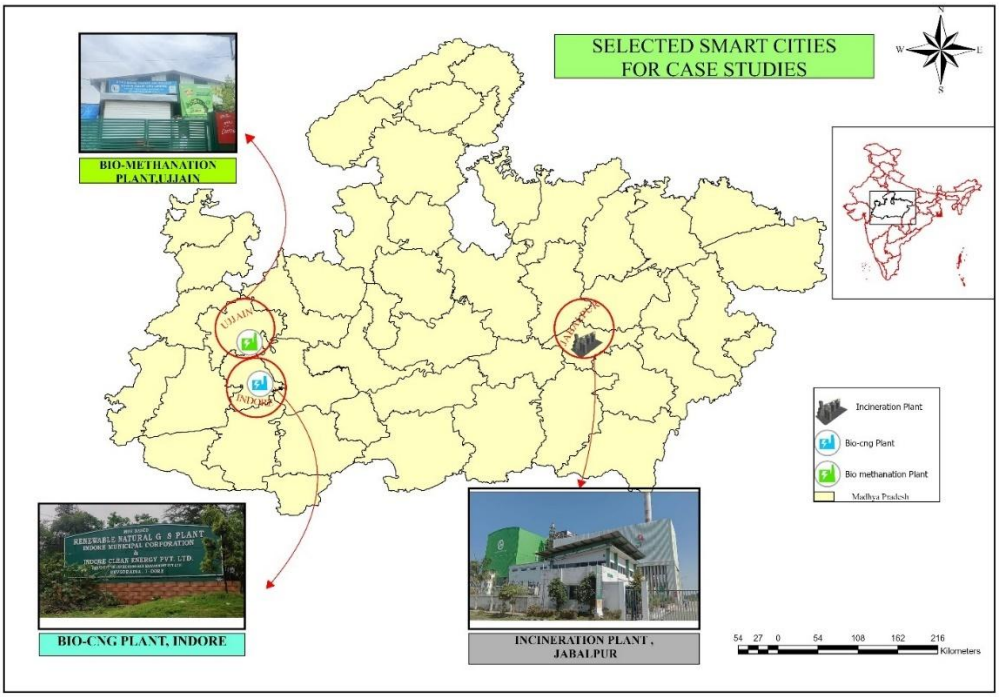


Figure 7: Smart cities and WTE interventions selected for case study

We used a mixed method approach in which both quantitative and qualitative data was collected and analyzed. Primary data was collected through interviews during field visits to three cities interacting with multiple stakeholders involved in the functioning of the plant (See Figure 9). The stakeholders we interviewed include Municipal Commissioners, Chief Executive Officers of Smart City Mission, officials and consultants of smart city mission, SWM experts, engineers and officials of the municipal corporation, plant managers, plant operators and engineers, workers in the plant, sanitation workers, experts and staff of Integrated Command and Control Centre (ICCC), resource persons of Swachh Bharat Mission, NGO representatives and common public. Secondary data was collected from academic literature, government and non-government reports and the data bank shared by the MoHUA. The techno-economic and emission details collected from the plant were used for quantitative impact assessment indicators. The qualitative data was analyzed by thematic analysis of interview transcriptions.



Figure 8: Snapshots from field visits

3. National Level Theme-based Impact Assessment Inferences

3.1 Implementation of WTE technologies by Smart Cities

Under the Smart City Mission, out of 94 smart cities, only 15 smart cities have implemented WTE plants (Figure 9). A total of 16 waste to energy plants have been implemented. Of this, 9 cities have implemented bio methanation plants that include Bhopal, Chandigarh, Chennai, New Town Kolkata, Panaji, Surat, Ujjain and Indore. Indore city has implemented two decentralized bio methanation plants utilizing the SCM funds. 5 of the implemented bio methanation plants are of small scale (5 TPD capacity), 2 of medium scale (15 and 20 TPD) by Indore and only one bio methanation plant is of larger capacity implemented by Surat (50 TPD). 4 cities have set up incineration plants that include Jabalpur, Salem, Shillong and Vadodara. 4 cities (Vadodara, Shimla, Rajkot and Jaipur) are generating Refuse Derived Fuel (RDF) that can feed into cement processing or coal power plants as fuel. The incineration plant and RDF are of larger and widely varying capacities ranging from 50 TPD to 1000 TPD. The WTE interventions in smart cities are therefore mostly decentralized bio methanation plants, followed by centralized incinerators and RDF plants of larger capacities.

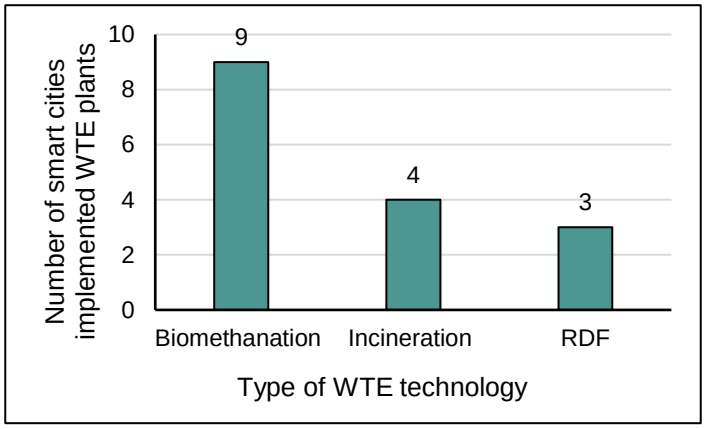


Figure 9: Types of WTE technologies implemented by Smart Cities

3.2 Lack of Source segregation in smart cities

Segregation at source is the key for the success of any waste related interventions and particularly, WTE plants. The success rate of WTE plants in India has been poor, due to lack of quality feedstock. Ensuring source segregation is therefore the most crucial aspect for smart cities to implement WTE plants. However, out of 100 smart cities only 47% of the cities have data on percentage of segregation at source. Of this, only 20 cities have attained more than 80% of segregation at source, while 14 of the cities have attained it between 50% and 80% and for 13 cities, it is still below 50% (See Figure 10). Smart cities should therefore prioritize segregation of waste at source before implementing any waste to energy interventions.

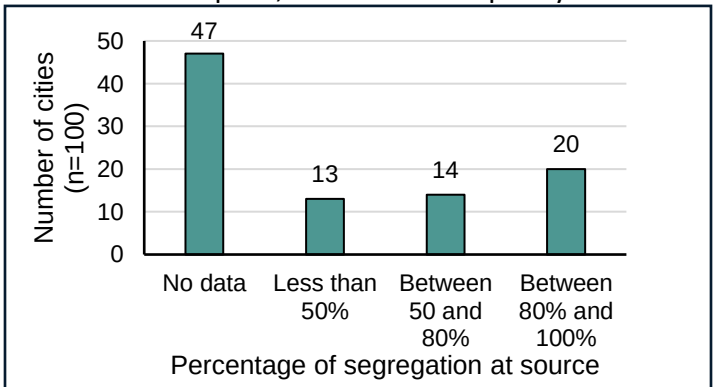


Figure 10: Percentage of source segregation in smart cities

3.3 Waste composition in smart cities

The techno-economic viability of any waste processing technology is dependent on the waste quantity and composition. However, 77 of the 94 smart cities in India does not have the data on waste quantity and characteristics. It is important to conduct regular waste audits to characterize MSW to review its suitability before adopting any waste to energy conversion technologies. These waste audits should capture the seasonal variations and waste flows across the municipal administrative boundaries.

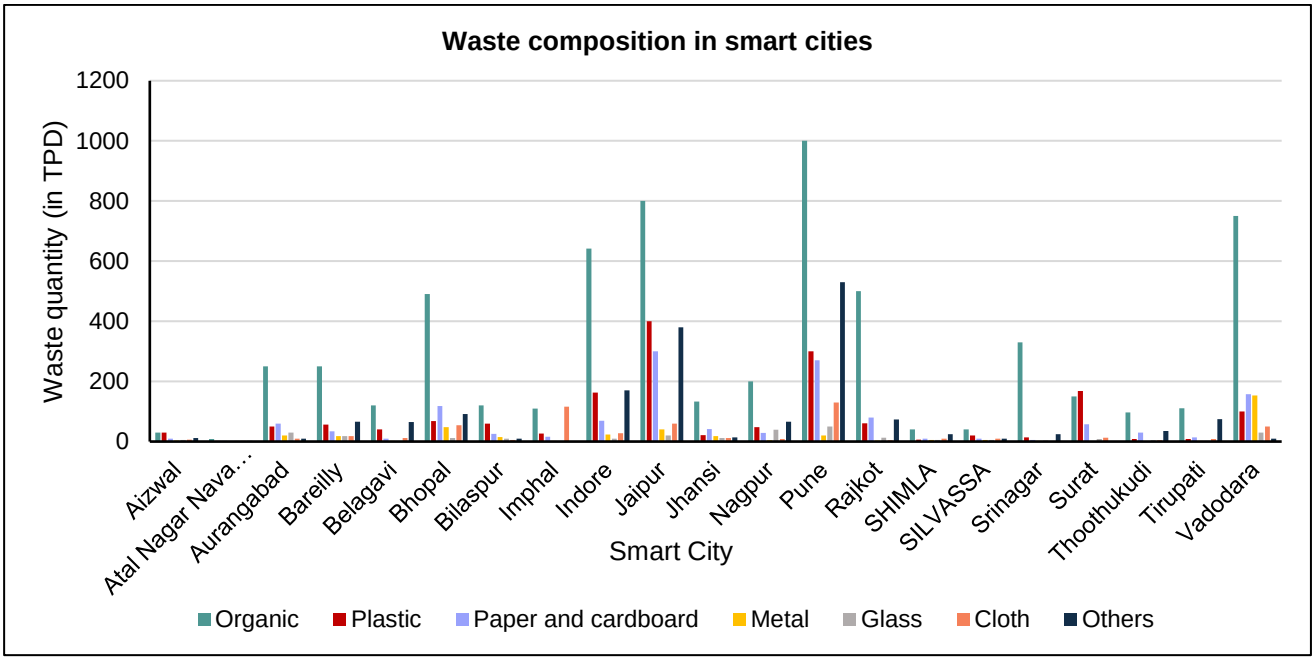


Figure 11: Waste composition in smart cities

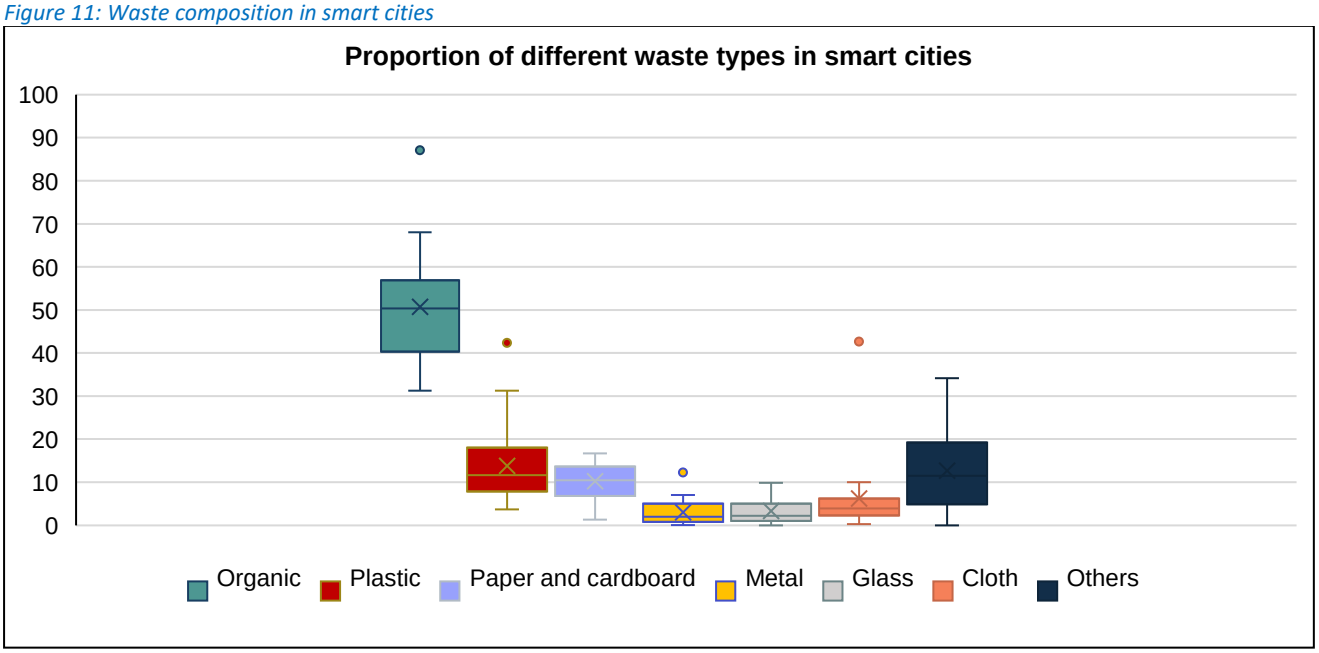


Figure 12 Proportion of different waste types in smart cities

The waste composition of smart cities in India shows that around 40-60% of waste is organic in nature, while plastic waste accounts for 8-18%, paper and cardboard 7-14%, metal 2-5%, glass 2-5%, cloth 3-6% and others 5-20% (Figure 12 & 13). This implies that a major proportion of the MSW produced in the cities are organic in nature, which has the lowest calorific value compared to plastic, paper and cardboard (See Appendix 3). This indicates that anaerobic digestion would be a better WTE option compared to incineration in Indian smart cities as incineration requires a minimum calorific value of 1600 kCal/kg and large quantities of waste for the plant to run at its operational efficiency. Further, the high calorific wastes like paper and cardboard, plastics and textiles are also recyclable wastes. According to waste hierarchy, SWM rules 2016 and many studies (Tan et al., 2014; Ouda et al., 2016), recycling is the more sustainable compared to energy recovery. Since incineration often is economically viable at larger capacities, it often takes hold of the whole waste chain adversely affecting the recycling sector. Therefore, smart cities should carefully consider the waste characteristics (calorific value, moisture content, fixed carbon, volatile matter etc.) while deciding on WTE technologies to ensure its long-term sustenance.

3.4 Utilization of funds by smart cities for SWM

At the national level, a total of 354 solid waste management projects have been completed wherein Rs.1,995 crores have been invested through SCM, additionally projects amount to Rs.963 Cr have been invested through PPP mode across 88 smart cities. Of the total fund that has been utilized for SWM, only 8% has been utilized for WTE plants. 63% of the fund is allotted for setting up waste collection and transportation infrastructure. This is followed by management of legacy waste where 14% of the fund is allotted. The waste segregation units and processing facilities including WTE plants get a minimal share of 5% and 14% respectively (Figure 14). A similar pattern is observed in various studies while analyzing the expenditure of ULBs in SWM in India. This shows that Indian cities tend to invest more in waste collection and transportation and are yet to invest in scientific waste treatment or processing facilities, which is important for transition to a circular economy.

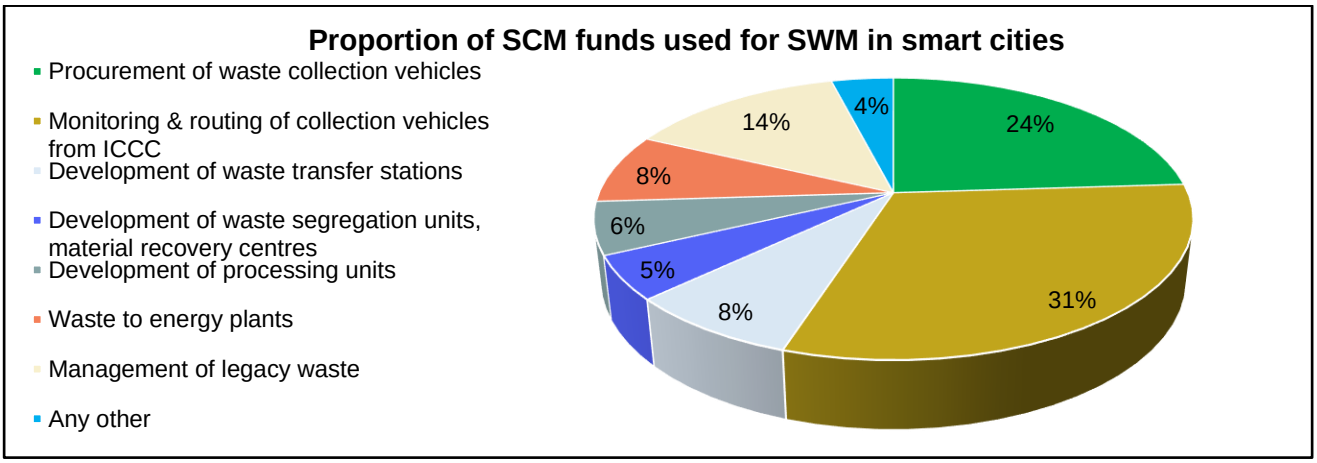


Figure 13: Proportion of SCM funds used for SWM in smart cities

4. Case Studies: City Visits & Detailed Primary Assessment

4.1 Centralized Bio CNG plant in Indore Smart City

4.1.1 Indore: City Profile

Indore smart city is the most populous city in the state of Madhya Pradesh, with its urban population recorded at 29,39,974 (Census of India, 2011). The Indore Municipal Corporation (IMC) covers a geographical area of 276 km² (Figure 14). Indore is divided into 19 administrative zones and 85 wards. The city of Indore has been recognized as the cleanest city in the country, consistently maintaining its number one position in the Swachh Survekshan Survey since 2017.

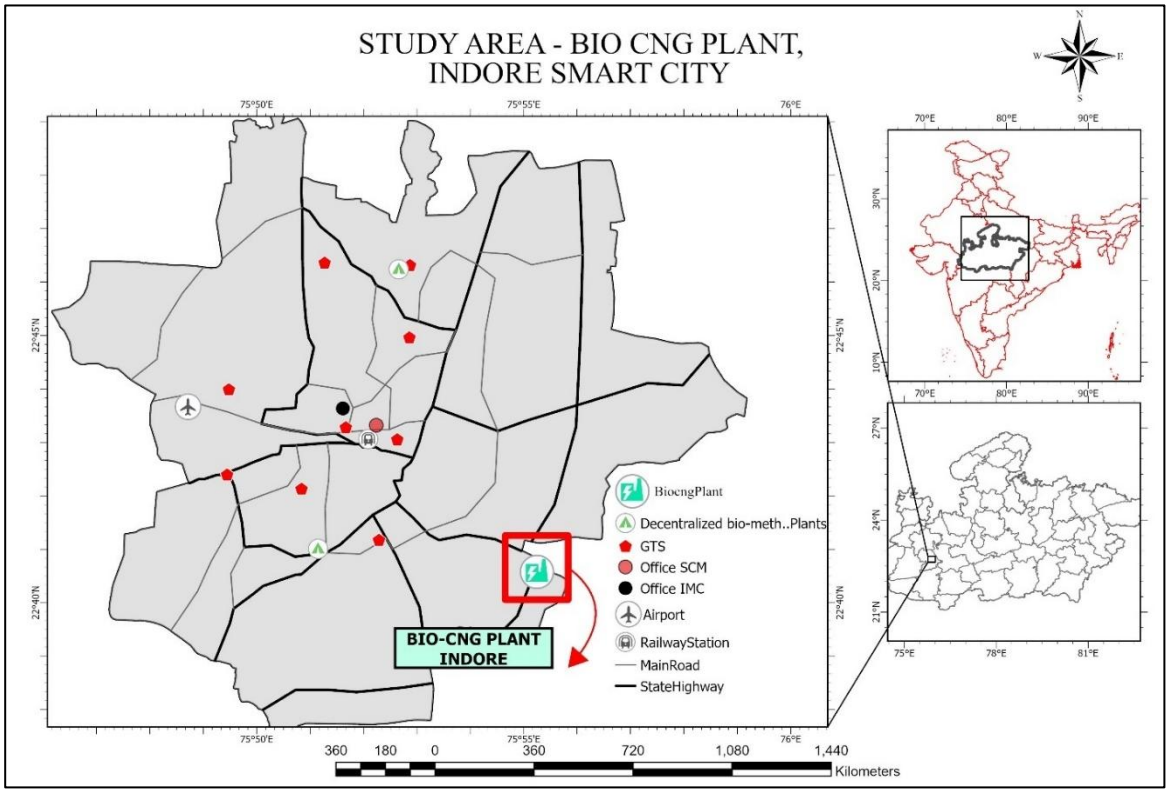


Figure 14: Study area: Indore municipal boundary with locations of SWM facilities
Source: Authors

4.1.2 Municipal Solid Waste Management (MSWM) in Indore

As per the latest estimates, Indore generates approximately 1125 metric tons of waste daily. Before 2016, the whole of the city's unsegregated waste was transported to the trenching yard in Devguradia village resulting in unhygienic conditions, increased pollution, and adverse public health impacts. The pressure from citizens, political will and bureaucratic competence marked a turning point, leading to an overhaul of Indore's waste management system. Now the Devguradia dump yard is completely reclaimed within five years in 2022 and a Bio CNG plant and recycling facility is established in the area to process the wet and dry waste produced in the city respectively (See Figure 15).



Figure 15: SWM in Indore: Before and after landfill reclamation

Source: The Better India, 2019

Indore's transformation began with a campaign to educate and engage its resident's on source segregation. With active participation from community and NGOs, today, IMC has attained 100% door to door collection and 100% source segregation, where households and commercial establishments segregate waste at source into six categories: Wet or organic, plastic, non-plastics, e-waste, sanitary waste and domestic hazardous waste. The source segregated waste from households and commercial establishments is transported to the Garbage Transfer Stations (GTS) and further taken to the decentralized and centralized bio methanation plants and material recovery facilities (MRF). Wet waste is converted to bio-CNG and compost and the dry waste is diverted for recycling. MSWM in IMC is summarized in Figure 16.

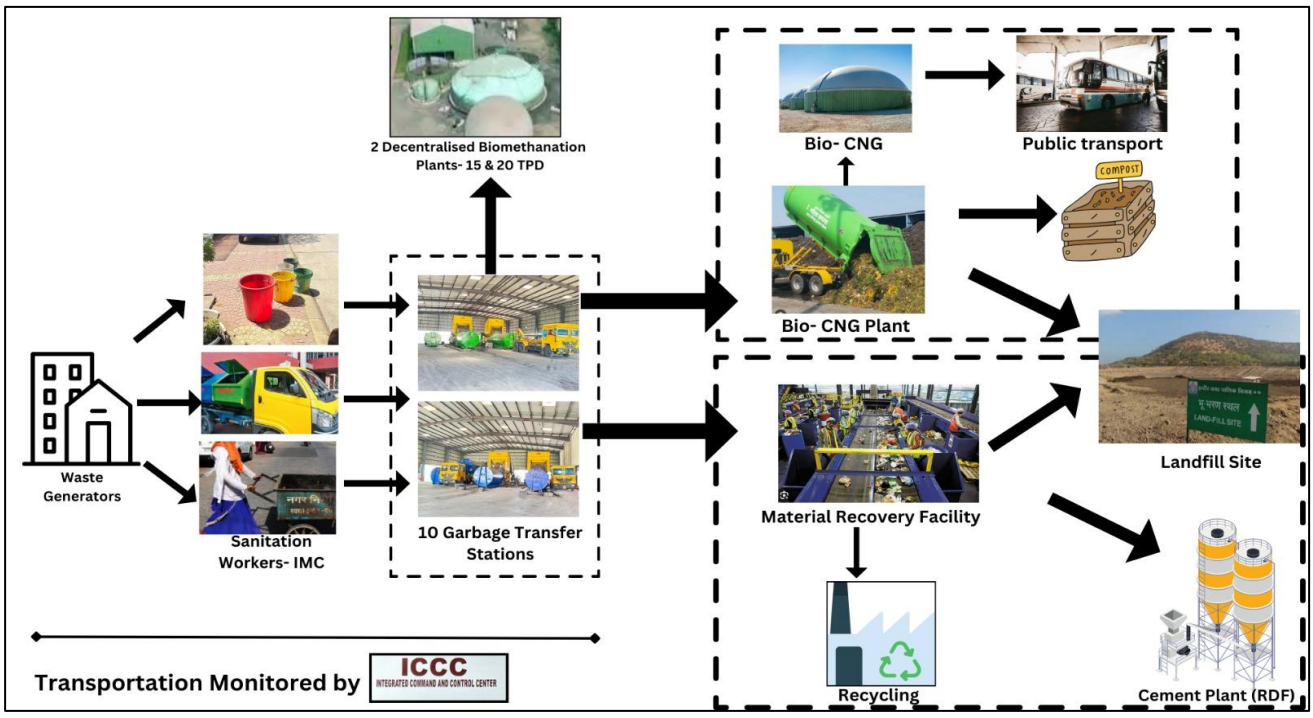


Figure 16: MSWM in Indore

Source: Authors

Figure 17 shows the waste flow diagram in the city of Indore. It can be found that 38% of total waste is recycled, 46% is converted to energy through bio methanation, only 5% is incinerated, 2% landfilled and 9% is unaccounted for. This indicates that around 89% of the waste is diverted off the landfill/open dumps and is flowing in a circular path. It was found that the centralized Bio CNG plant and decentralized bio methanation plants treats almost 100% of wet waste collected in the city. 95% of the collected dry waste after secondary segregation at MRF is diverted for recycling.

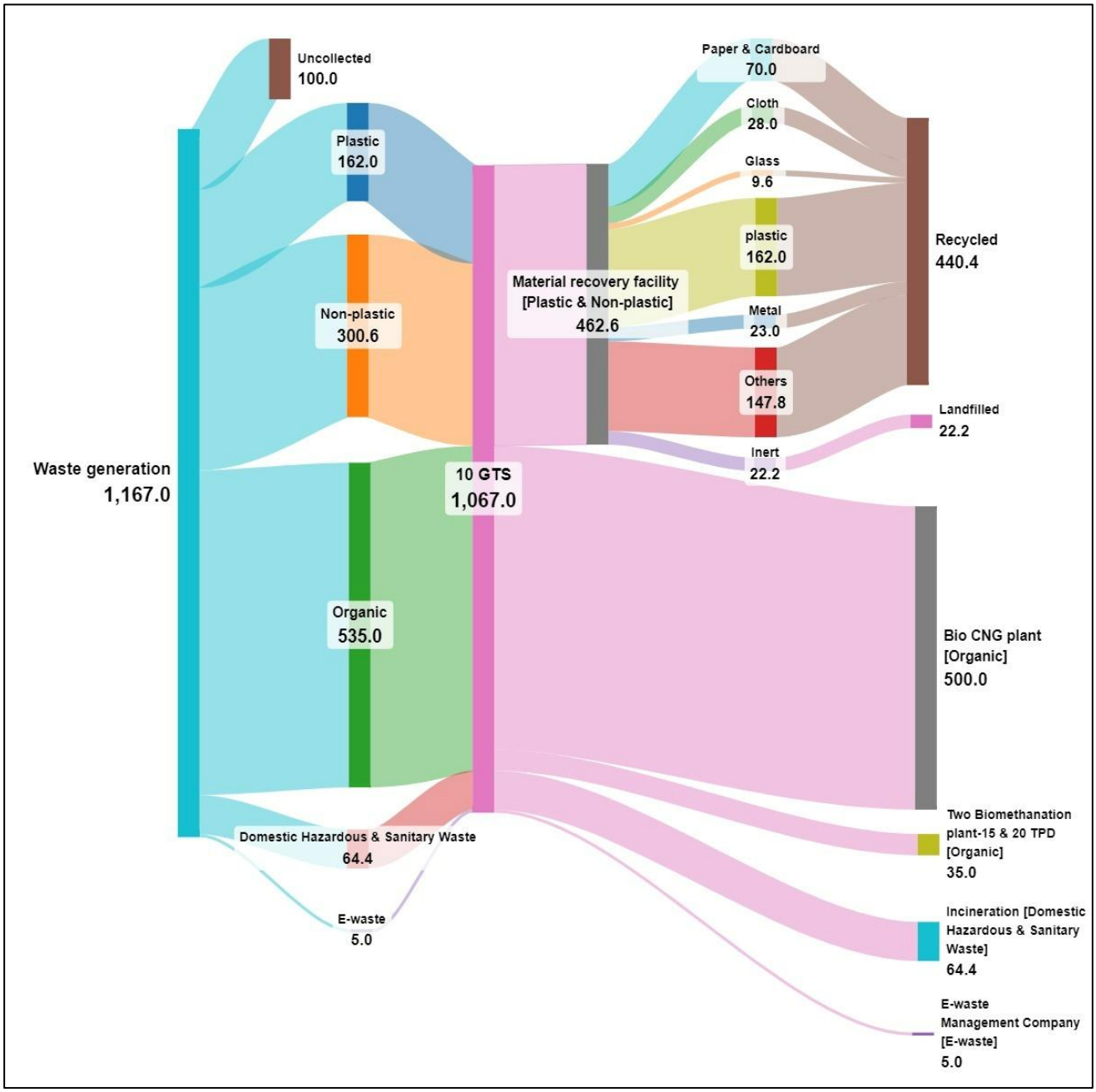


Figure 17: Sankey diagram to depict the waste flow in Indore

4.1.3 WTE plant in Indore

The bio-CNG plant in Indore is of 550 TPD capacity and is Asia's largest bio methanation plant, operational since February 2022 (See Figure 18). The process flow diagram of the plant is shown in the Figure 19 and Figure 20. Out of the 642 TPD of total wet waste generated in the city, 78% is treated in this plant, producing 16-17 TPD of bio-CNG, and producing 35600 tons of compost annually. 50% of bio-CNG produced in the city is used for fueling 200 city buses of Indore Municipal Corporation, 40% is sold to oil marketing companies and 10% is sold to local commercial customers. The plant is installed and operated in the 15 acres municipal land by Indo Enviro Integrated Solutions Ltd (IEISL)[2] on Design, Build, Finance, Operate and Transfer basis in PPP mode for a concession period of 20 Years with Indore municipal Corporation (IMC). It works on a revenue model (See Figure 21) where IEISL pays a royalty of INR 2.52 Cr annually to IMC for provision of quality waste and IMC also purchases a minimum of 50% of the Bio CNG produced at a rate of Rs 5 per kilo less than the market rate. The company gets its revenue from the sale of Bio CNG, fertilizers and carbon credits. The project is reported to have an Internal Rate of Return (IRR) of 21.6%.



Figure 18: Bio CNG plant in Indore

[2] IEISL is 100% subsidiary of Everenviro Resources Management Pvt Ltd which is again 100% subsidiary of GGEF (Green Growth Equity Fund) and a company engaged in Solid Waste Management encompassing municipal organic waste, agro residue and agro industrial waste

Source: Indore Smart City Development Office, 2024

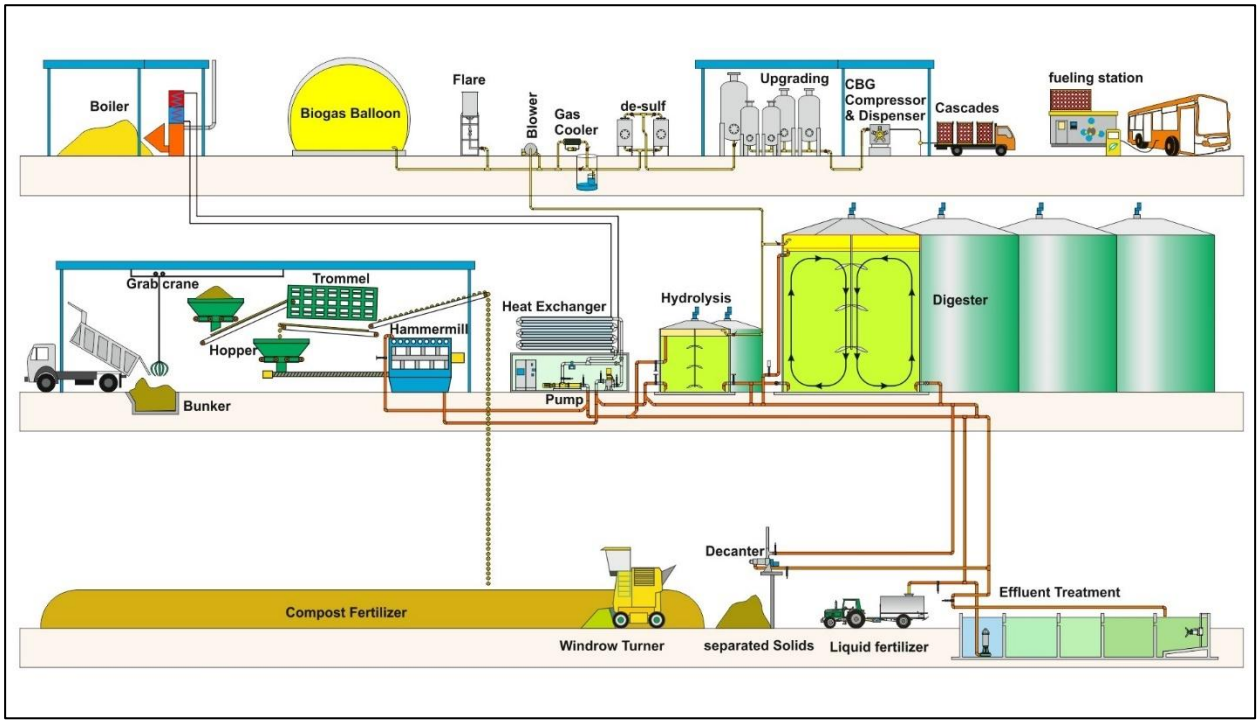


Figure 19: Process Flow Chart, Bio CNG plant Indore

Source: Plant operator, Everenviro- IEISL, 2024

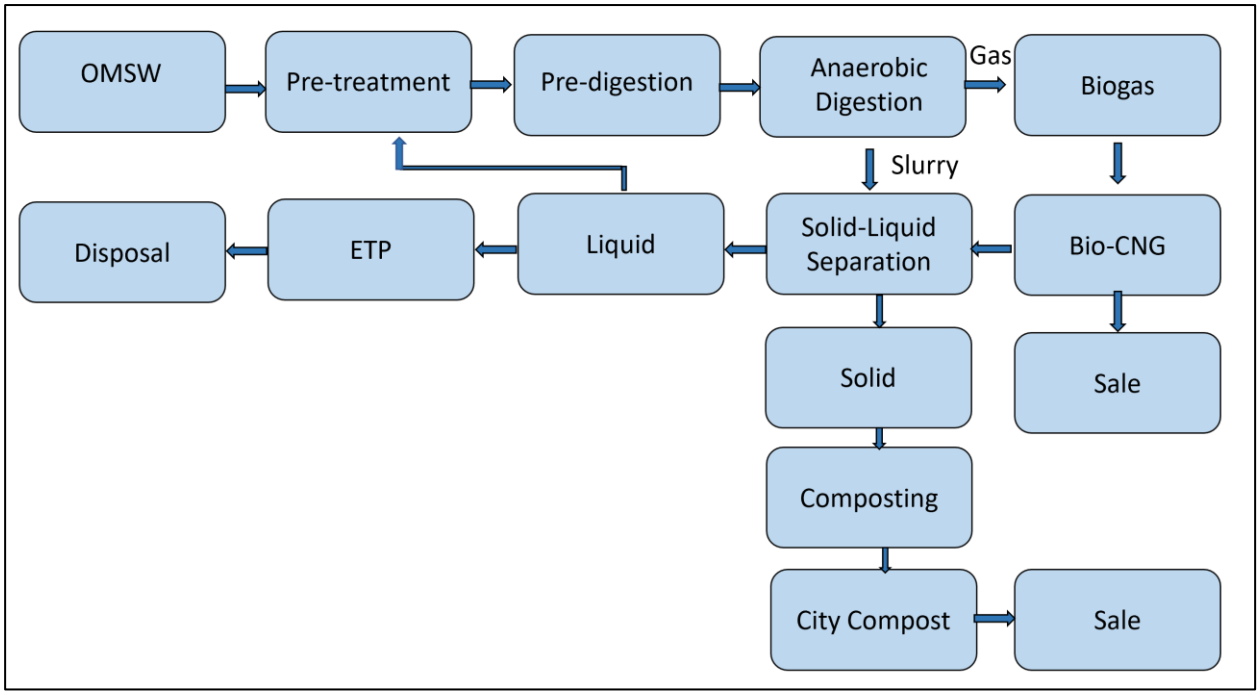


Figure 20: Process Flow Chart, Bio CNG plant Indore

4.1.4 Stakeholders involved and Role of SCM in SWM in Indore

The major stakeholders and their role involved in the functioning of the plant is given in Figure 21. The SCM is not involved directly in the day-to-day operations of the Bio-CNG plant but has facilitated its function by building supporting infrastructure.

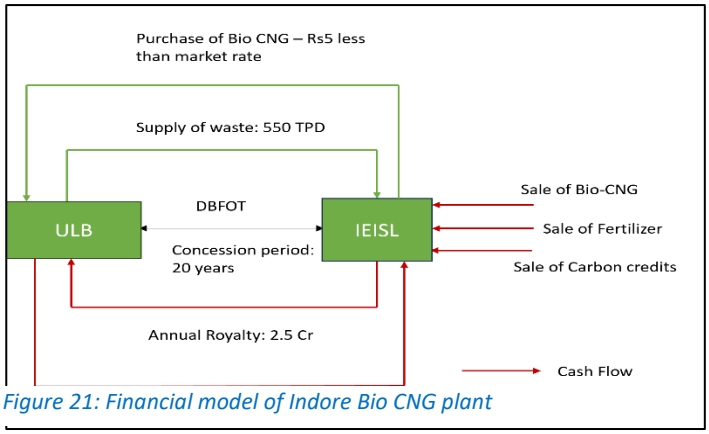


Figure 21: Financial model of Indore Bio CNG plant

The SCM in Indore has invested a total of INR 150 Crores to enhance the SWM in the city. This includes establishing an Integrated Command and Control Centre (ICCC) that performs monitoring and routing of waste collection vehicles, development of waste transfer stations, MRFs, processing centers, small scale bio methanation plants and reclamation of dump yard by removing the legacy wastes. However, its role is often limited to fund provision in setting up waste related infrastructure. Once established, the infrastructure is gradually handed over to IMC (being the primary responsible body for SWM as per SWM rules 2016) which undertakes the operation and maintenance of the infrastructure.

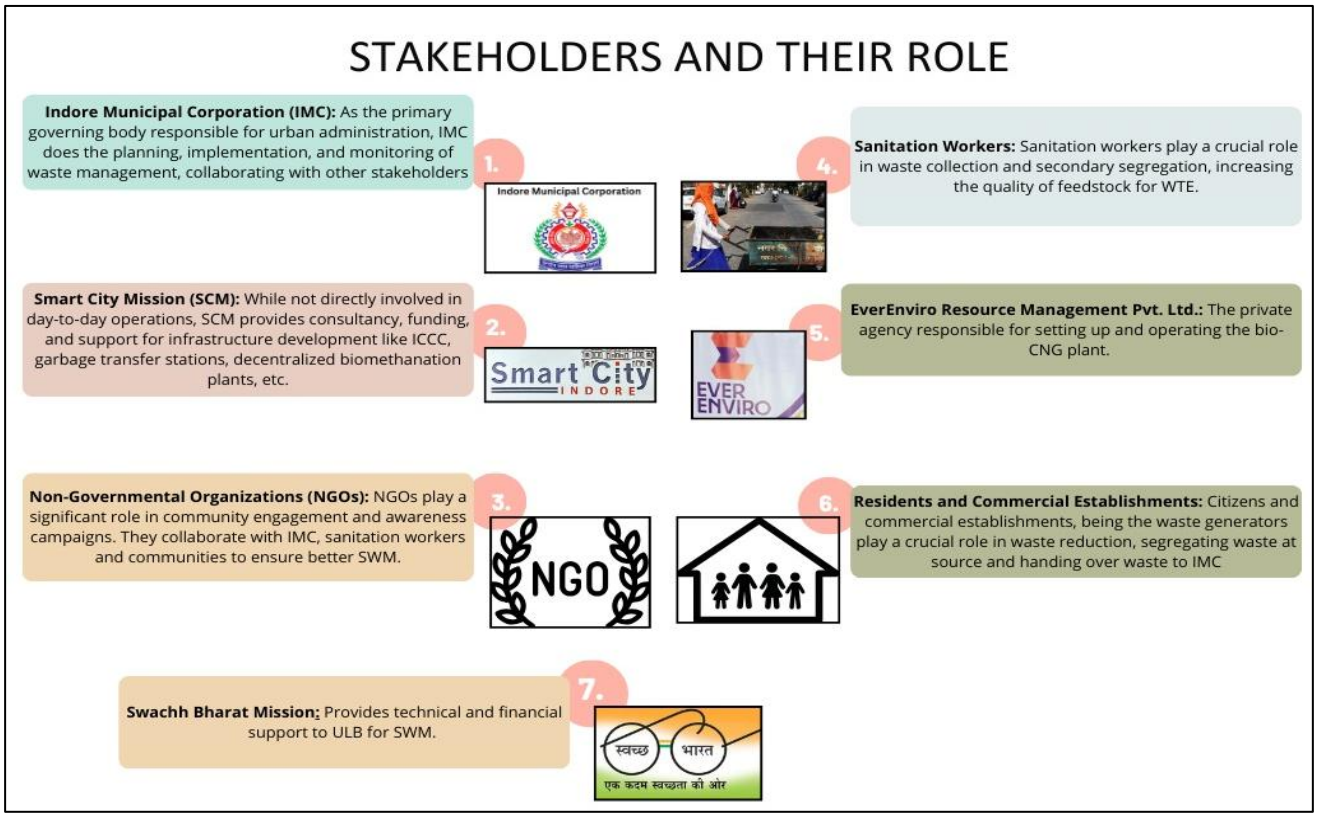


Figure 22: Stakeholders and their role in MSWM, Indore

Source: Authors

4.1.5 Impacts

Environmental impacts: **Reduction in Green House Gas emissions**

Table 3 shows the different types of annual GHG emission reductions with functioning of the plant.

i) By generating Bio CNG from waste, replacing coal-based diesel, the plant contributes to net annual GHG emission reduction of 20259 tons of CO_2 eq[3].

ii) Diverts 500 TPD waste from landfills reducing annual GHG emissions of 191146 tons CO_2 eq[4].

iii) Slurry generated, which is a byproduct of Biogas generation can replace chemical fertilizers, accounting for reduction in annual GHG emissions of 1221 tons of CO_2 eq[5].

iv) Net GHG emission reduction is found to be positive as 206049 tons of CO_2 eq. Major contribution is by diverting MSW off the landfills (90%), followed by diesel substitution (9.5%). The contribution by fertilizer substitution is found to be minimal (0.5%).

Table 3: Annual GHG emission reduction due to the Indore Bio CNG plant

Type of emissions	Annual emissions in tones CO_2 eq.)
Direct emissions during the process of waste to energy conversion	-183
MSW diversion	191146
Diesel substitution	20259
Fertilizer substitution	1221
Transportation of waste[6]	-3253
Electricity consumption at the plant[7]	-3141
NET GHG emission reduction	206049

Minimal pollutant emissions to air

The direct emissions involved in the process of anaerobic digestion is minimal, as the plant is assumed to be well-maintained and therefore the methane leakages would be minimal[8]. It is to note that in case of lack of maintenance, methane leakages can be higher contributing to higher GHG emissions (Singh & Kalamdhad, 2022).

[3] 1 tonne of CBG can replace 1.01479 tons of diesel (Singh & Kalamdhad, 2022). 17 TPD bioCNG is produced from the plant which can replace 17.25143 tons of diesel = 20,710 liters of diesel (density of diesel 0.833 kg/L).
Fuel energy consumption (MJ) (Transport associated) = Diesel used in L*EC $_{diesel}$, where EC $_{diesel}$ = Energy coefficient/calorific value for diesel = 36.12 MJ/L.
CO_2 eq. GHG emissions (kg) (Transport associated) = Diesel used in L * 2.68 (Emission factor for diesel) (IPCC, 2006; Patel et al., 2023).

[4] Emission reductions by prevention of MSW landfilling were calculated using the methane commitment model and IPCC (2019) default factors.

[5] Biogas produced at the plant = 42500 m^3 per day. Solid slurry produced at the plant= 245000 kg per day (Source: Plant engineer). Now, NPK fertilizer to slurry replacement ratio is 75.7: 1 (Kaushik et al., 2023). Amount of NPK fertilizer that can be replaced = 245000/75.7 = 3236 kg of NPK fertilizer. Replacing 1 kg of NPK fertilizer results in emission reduction of 2.85 kg CO_2 eq. 1 kg slurry produces 0.024 kg CO_2 eq. Emission saved from such replacement = (2.85*3236) - (0.024*245000) = 3344 kg CO_2 eq per day.

[6] Diesel consumption per day for waste transportation in Indore = 3325 litres. Emission factor for diesel = 2.68.

[7] Electricity required to produce 1 cubic meter of raw biogas= 0.25 kWh (Global green Growth Institute (GGGI), 2023; Singh & Kalamdhad, 2022). Grid emission factor = 0.00081 t CO_2 eq per 1 kWh (CEA, 2014).

[8] Assumed to be only 5% as per IPCC default value.

Pollutant emissions to water

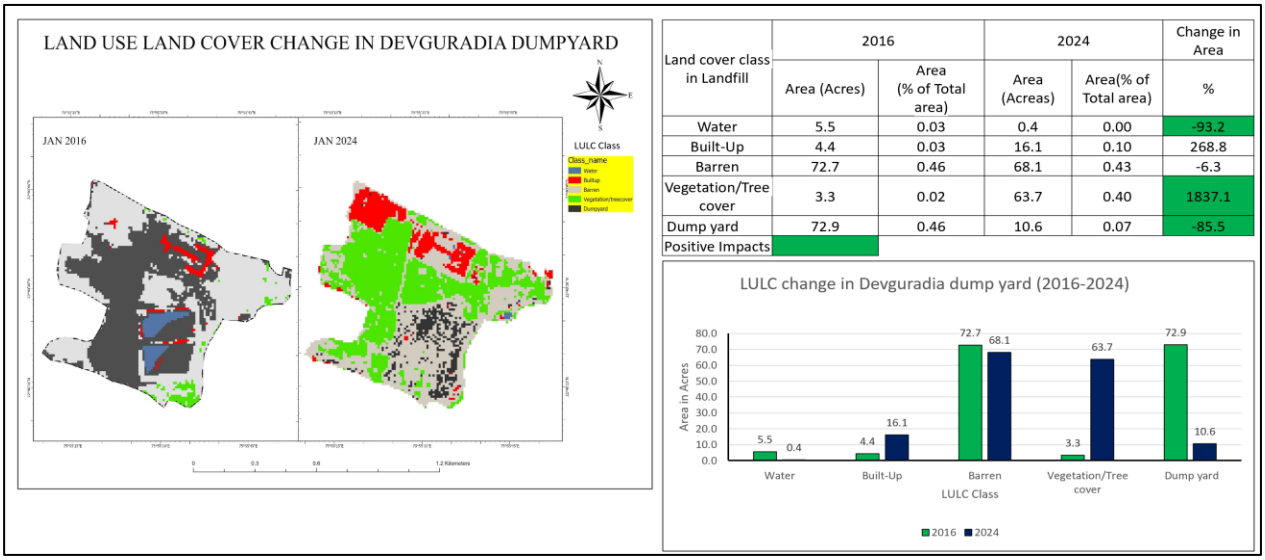
The water quality data at the outlet of the plant was not available. However, it is claimed by the plant operators that the waste water is treated in an effluent treatment plant before disposal. The water quality data from borewells located within 200 metres of the WTE plant in Indore reveals very poor conditions, with a Weighted Average Water Quality Index of 258 in 2018 and 253 in 2021. This poor quality can be attributed to the legacy waste which was present in the Devguradia dumping yard for several years. However, since the dumping yard has now been reclaimed and the WTE facilities are established, it is anticipated that better water quality may be observed in the coming years as the environmental impact of the legacy waste diminishes.

Improved ecosystem services due to dump yard reclamation and urban forest plantations:

The Bio CNG plant in Devguradia treats a total of 78% of the waste generated in the city. This level of waste treatment has facilitated the reclamation of the erstwhile dump yard through tree plantation initiatives or urban forest within the Devguradia plant. A land use and land cover (LULC) change analysis of the Devguradia dump yard before and after the plant's intervention in 2016 and 2024, respectively is conducted to quantify the changes. The results are given in Figure 23. Initially, the dump yard area covered 72.9 acres, constituting 45.9% of the plant boundary. Following the introduction of the plant, the dump yard area was significantly reduced by 85.5% from 2016 to 2024, now spread to only 7% of the plant's total area. In accordance, the vegetation or tree cover within the plant increased significantly by 1837.1%, expanding from an insignificant 2% to 40% of the plant boundary. Also, the landfill, initially covering 3% of the area (2016), was significantly reduced by 93.2% due to the introduction of Bio CNG plant's implementation. The observed increase in built-up area, as per the LULC map, can be attributed to the construction of the Bio CNG plant and the MCF.

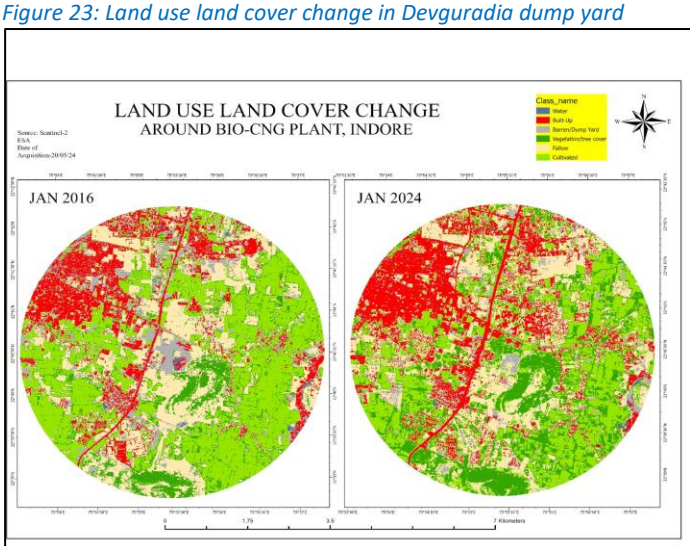
The increase in urban green cover, such as tree cover, is an important step toward environmental sustainability, counteracting climate change. This increase can result in carbon sequestration, improved air quality, flood control, and water recycling, among other benefits. Tree cover has been proven to reduce PM2.5 concentrations and improve regional air quality (Oliveira et al., 2022; Xu et al., 2020). The conversion process promotes soil fertility and nutrient cycling, facilitating organic matter accumulation and microbial activity, which are essential for ecosystem health (Liu et al., 2018). Additionally, it helps mitigate urban heat island effects, which is particularly important for a city like Indore, located in the subtropical Malwa plateau of Madhya Pradesh. Indore has experienced a rapid decadal increase in built-up areas by 60.8% (2010-2020), expected to extend to 58% of the area occupied by urban built-up land by 2025, with temperatures reaching 50°C in certain parts of the city during summer (Gohain et al., 2023).

Land Use Land cover change around the WTE plant



Land cover class in Landfill	2016		2024		Change in Area
	Area (Acres)	Area (% of Total area)	Area (Acreas)	Area(% of Total area)	%
Water	5.5	0.03	0.4	0.00	-93.2
Built-Up	4.4	0.03	16.1	0.10	268.8
Barren	72.7	0.46	68.1	0.43	-6.3
Vegetation/Tree cover	3.3	0.02	63.7	0.40	1837.1
Dump yard	72.9	0.46	10.6	0.07	-85.5
Positive Impacts					

Figure 23: Land use land cover change in Devguradia dump yard



LULC class	2016		2024		Percentage of change
	Area (sq. km)	Share %	Area (sq. km)	Share %	
Water	0.11	0.00	0.11	0.00	0.00
Built-Up	5.01	0.10	7.10	0.13	41.72
Barren	4.29	0.09	2.56	0.05	-40.33
Vegetation/tree cover	3.61	0.08	6.03	0.11	67.04
Cultivated	11.68	0.24	8.89	0.17	-23.89
Fallow Land	7.96	0.17	7.96	0.15	0.00

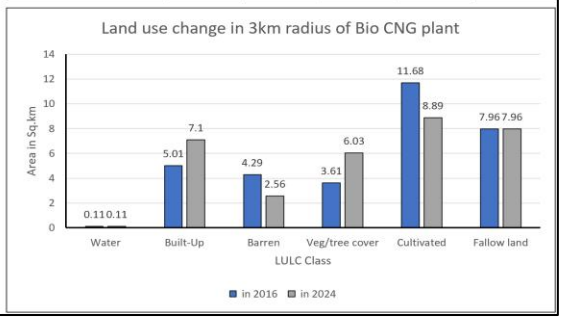


Figure 24: Land use land cover change in 3 km radius of the Bio CNG plant

LULC change in 3 km radius of the plant area (Figure 24) shows a noticeable 41.7% increase in built-up area and 67% in dense vegetation cover (2014-2024) in the near proximity of the bio-CNG plant as shown in the map. This indicates a transition towards habitation and infrastructure development in the vicinity. Given the geographical proximity has a strong relationship in the perception of residents regarding landfill, due to the various risks associated with the unscientific land fill (Roy et al., 2023), It suggests that the region is more livable and conducive to human settlement, potentially due to the removal of dump yard and its conversion to tree cover and implementation of sustainable waste management practices. This change reflects the **growing importance of the Devguradia area as a residential and commercial hub**, particularly with its proximity to the highway.

Economic impacts

i) The plant pays a royalty amount of INR 2.5 Cr to IMC annually for supply of wet waste, contributing to cost recovery for the ULB in SWM. Further, replacing diesel with Bio CNG for transportation results add to the annual cost recovery of ULB by INR 16.5 Cr. 9
ii) The net present value of the plant is found to be positive (+88 Crores). Even though the capital (150 Cr) and operational costs (25 Cr per annum) are high, there is revenue generation in the form of sale of Bio CNG (33.2 Cr per annum), compost (6.6 Cr per annum) and carbon credits (13 Cr).
iii) The profitable operation of the Bio-CNG plant in Indore has attracted additional private players to the field. Furthermore, Indore's acclaimed status in waste management has led to increased private sector investments, including Corporate Social Responsibility (CSR) contributions. Indore city has become a fertile ground for private sector investments in SWM.

Social impacts

iv) The Bio-CNG plant in Indore has created approximately 100 skilled jobs for local residents, providing workers with regular income, social security benefits, and healthy working conditions, with no reported health issues so far. However, the working conditions for those involved in waste collection and transportation require significant improvement. Many of these workers are unaware of the social security benefits available to them, despite their provision. Urban Local Bodies (ULBs) must take responsibility for creating awareness and ensuring access to these benefits. Additionally, a lack of basic amenities such as drinking water and sanitation facilities has been reported. Given that these workers play a critical role in the plant's functioning—by ensuring that segregated waste reaches the facility—it is essential to prioritise their well-being.
v) The social acceptance of the Bio-CNG plant is comparatively better, as it has replaced the earlier Devguradia dumping yard, which had severe public health and environmental impacts. While the outcomes have been more favourable, residents in the vicinity remain concerned about issues such as odour and flies, which affect their quality of life. Addressing these concerns through effective odour control and pest management will help sustain and enhance public support.
vi) Centralized waste management facilities, while effective in keeping city centres clean, often impose significant burdens on peripheral areas. Communities near these facilities, such as in Indore, continue to face issues like odour and flies, highlighting the drawbacks of centralized systems. To address this, it is crucial to promote decentralized waste management. Decentralized systems distribute waste processing equitably across urban areas, reducing the environmental and social impacts on specific communities while improving overall waste management efficiency.

[9] Assumptions. Cost of 1 litre diesel = INR 90. Procurement rate of 1 kg Bio CNG = INR 56. 8500 kg of Bio CNG is procured by IMC everyday. 1 tonne of CBG can replace 1.01479 tons of diesel (Singh & Kalamdhad, 2022). 8.5 tonne replaces 8.6 tonnes diesel = 10324 litres. Per day cost savings to IMC in transportation= (10324*90-8500*56)= INR 4, 53,160 per day. Annual cost savings = INR 16.5 Cr.

vii) The informal waste pickers have been integrated into the formal SWM system in Indore to some extent, although they are not directly involved in the operation of the Bio-CNG plant. Their roles include building awareness, handling documentation, and performing segregation and cleaning activities at the Garbage Transfer Stations (GTS) and Material Recovery Facilities (MRFs), facilitating plant's operation. They have been provided with uniforms, ID cards, safety equipment, and some social security benefits. Over time, this integration has led to increased social acceptance, dignity, and recognition for these workers.

4.1.6 Success factors

i) **Source segregation is the key:** India's Municipal Solid Waste (MSW) typically exhibits a low volatile solid content of 41.3%, leading to a modest feedstock-to-gas conversion ratio of 100:2.3 (Kaushik et al., 2023). The feedstock generally comprises a mixture of food, fruit, yard, and paper waste, with a low methane yield of 55%. In contrast, Indore excels with a volatile solid content of 99%, achieved through effective source segregation practices. This high quality of waste has been instrumental in the successful operation of the Bio-CNG plant. According to the private operator, Indore was chosen over other cities because a comparative study revealed superior waste quality due to rigorous segregation at the source.

ii) Waste to energy as part of an integrated system: In Indore, the WTE facility is one component of a comprehensive waste management system that addresses various waste streams. Wet waste is processed at the WTE plant, along with multiple decentralized facilities. Material recovery facilities focus on recycling, e-waste is processed separately, and hazardous waste, including sanitary napkins, is incinerated. This multi-facility approach ensures that different waste streams are managed effectively, highlighting the importance of an integrated system in achieving sustainable and efficient waste management.

iii) **Community involvement** is a crucial strength in SWM in Indore. IMC has actively engaged NGOs in micro-level planning by dividing the city into 19 zones and implementing SWM initiatives at the grassroots level. The city's residents have high expectations for Indore to sustain its top position in the annual Swachh Survekshan survey, creating significant pressure on politicians and bureaucrats to maintain high standards. Since 2017, Indore has successfully achieved and sustained 100% source segregation, demonstrating the effective participation of the community in SWM service delivery.

iv) **Large scale investments in solid waste management:** Indore Municipal Corporation allocates up to INR 200 crore annually for waste management (Deccan Herald, 2024). The ability to invest significantly in waste management has been instrumental in establishing efficient systems that improve waste segregation, collection efficiency, and overall waste processing capabilities. However, this model, while effective in Indore, is difficult to replicate in other Indian cities, where financial constraints limit the capacity for such large-scale investments.

4.1.7 Challenges of Bio-CNG plant in Indore

Technical or operational challenges

i) **Changing waste composition** due to changing consumption patterns, seasonal variations and floating population, pose challenges for the digester. To produce usable biogas in meaningful quantities, the digester's internal conditions, including temperature and bacterial composition, must be closely controlled. Certain kinds of wet waste which are predominant in the city like coconut shells or remains of sugarcane are unable to be treated at the bio methanation plant. The presence of these sometimes damages the plant parts, increasing the replacement and maintenance costs. Many parts of the plant are imported and not made in India, which would further delay the operation of the plant and increase its maintenance costs.

ii) **Incompatibility of produced bio-CNG with the vehicles:** The Bio-CNG (with 95-96% purity) produced from the waste is found not 100% compatible to run the city buses. This mandates the mixing of pure CNG from other private agencies.

iii) **Distribution challenges due to tax disparities:** Differential tax structure between CBG and CNG poses a significant challenge in distribution. While CBG is taxed at a lower rate (5% GST), CNG faces higher taxes (14% VAT and 14% excise duty). CBG injected into pipelines might be taxed as CNG at a higher rate (28%), which affects the cost-benefit analysis and discourages gas distributors from utilizing the CBG- CGD synchronization scheme of SATAT.

Economic challenges

i) Centralized large-scale waste processing plants are often capital-intensive, requiring significant upfront investment. For instance, the plant in Indore has a capital expenditure (capex) of INR 150 crore, presenting a substantial economic challenge. Such high costs can be a barrier to scalability and financial feasibility, demanding careful consideration of funding sources, financial management, and long-term economic sustainability.

ii) Centralized large-scale waste processing facilities, while capable of handling substantial volumes of waste, incur substantial cost related to transportation. In Indore, around INR 11 Cr is spent annually on transportation of waste to the plant[10]. Many ULBs may find such high transportation costs unaffordable.

iii) Indore Municipal Corporation allocates up to INR 200 crore annually for waste management (Deccan Herald, 2024), a cost that is beyond the financial capacity of most Urban Local Bodies (ULBs) in India. This high expenditure presents a significant challenge for replicating Indore's waste management model in other cities.

[10] Approximately 3325 liters of diesel is consumed to transport waste to the plant everyday. Cost per liter is assumed to be INR 90.

Environmental challenges

i) Despite efforts by plant operators to control odor and flies, residents in nearby communities continue to report unpleasant smells and the presence of flies, a persistent challenge of any centralized waste treatment facility. This situation suggests potential public health issues, mandating the need for health studies focused on both plant workers and local residents. Moreover, it highlights the critical necessity for regular air quality monitoring in the area to better understand and address these impacts. The land use land cover change in the radial distance of 3km (see figure 24) indicates a growing urbanization with increased built ups in the proximity of the plant which further mandates the need to mitigate the adverse environmental consequences.

ii) Being a centralized facility, the waste transportation to the plant accounts for higher emissions. In Indore, the transportation emissions are equivalent to 3252 tons of CO_2 eq. annually[11].

Social Challenges

i) **Skilled Labor Demand and Displacement of Informal Workers:** The introduction of advanced waste processing facilities, such as Bio-CNG plants and mechanized Material Recovery Facilities (MRFs), has led to a growing need for skilled labor, as only skilled workers are equipped to operate these sophisticated systems. This shift has displaced many unskilled workers who previously transitioned from the informal waste sector into these roles. To ensure a more inclusive transition, it is essential to consider the integration of the informal waste sector by providing opportunities for skill enhancement and training, enabling these workers to adapt to new technologies and roles within the waste management framework.

ii) **Challenges Faced by Sanitation Workers and the Need for Improved Working Conditions:** Sanitation workers, who are crucial for the effective functioning of waste processing plants through their roles in sweeping and door-to-door collection, often face significant challenges in their working conditions. Key issues include a lack of awareness about the benefits provided by ULBs, exposure to occupational hazards such as dog bites, cuts, and wounds, and insufficient access to drinking water and sanitation facilities during work hours. Additionally, their reported income is often inadequate to meet their needs. These workers are fundamental to the success of any SWM system, highlighting the urgent need for strategies to identify and mitigate their health risks and enhance their overall working conditions.

[11] Fuel energy consumption (MJ) (Transport associated) = Diesel used in L*EC $_{diesel}$, where EC $_{diesel}$ = Energy coefficient/calorific value for diesel = 36.12 MJ/L.
CO_2 eq. GHG emissions (kg) (Transport associated) = Diesel used in L * 2.68 (Emission factor for diesel) (IPCC, 2006; Patel et al., 2023).

iii) **Land availability and people's resistance:** Land is a crucial factor for the operation of such large scale centralized facilities. More often this locates the plant to the city peripheries that bear the brunt of solid waste generated in the core city area. This is an inherent drawback of any centralized facility. While acquiring land on the outskirts sometimes may lead to community resistance due to concerns about environmental impacts and encroachment fears. Further, it is often found unjust for city peripheries to host waste processing operations that serve the urban center's needs. The opposition from people is often driven by legitimate apprehensions about air and water pollution, odor issues, and the potential reduction in land value. The community members living near these plants in the city outskirts are often already marginalized, further experiencing the negative externalities of waste processing without commensurate benefits. In the case of Indore, there was no community opposition to establishing the centralized waste management facility because the area was in a worse condition prior to the plant's operation due to an uncontrolled dumpyard. While the plant has improved the situation by systematically managing waste, the nearby community continues to experience problems with flies and odor, indicating ongoing challenges associated with a centralized facility.

Governance or institutional challenges

i) **Limited role of Smart City Mission in MSWM:** In Indore, the Smart City Mission (SCM) does not have a direct involvement in the functioning of Bio-CNG plant but has facilitated its operation indirectly by establishing i) an Integrated Command and Control Center (ICCC) that monitors the transportation of vehicles transferring collected waste from households and commercial establishments to the Bio-CNG plant and ii) waste segregation centers or material recovery facilities that conduct secondary segregation of dry waste. However, it was found that SCM's role in decision-making related to municipal solid waste management (MSWM) is minimal and is primarily limited to providing funds for the municipal corporation to implement waste infrastructure. This limited role falls short of the expectations set for SCM, which was intended to bridge gaps in existing technology and governance in waste management.

ii) **Lack of collaborative governance** : There is a lack of integration, with inconsistencies and overlaps in roles and responsibilities, as well as conflicts in visions and priority projects among the various institutions involved in MSWM: the Municipal Corporation, Swachh Bharat Mission (SBM), and Smart City Mission (SCM). The Municipal Corporation, as the primary entity responsible for implementing MSWM, remains the major decision-maker, utilizing funds and resources from SCM and SBM. Once a project is implemented using SCM funds, the Municipal Corporation manages its operations and maintenance, with any revenue generated

also directed to the Municipal Corporation. This leaves the role of SCM uncertain after the project's implementation. Furthermore, this situation of limited ownership in the projects reduces the enthusiasm and interest of SCM authorities. The unclear roles and ambiguities in operations present major governance challenges, hindering effective coordination and integration of efforts among the stakeholders. The conflicts arise from the fragmented structure of urban institutions. What is needed are institutions equipped with updated regulations to foster collective decision-making, promoting greater clarity in roles and responsibilities and reducing ambiguities in operations.

iii) **Difficult to generate revenue for SCM from SWM projects**: The Smart City Mission (SCM) is mandated to become financially self-sustaining within five years, necessitating significant revenue generation from its projects. However, as Solid Waste Management (SWM) is primarily the responsibility of the Indore Municipal Corporation (IMC), which is the largest spending agency on SWM, it also retains the primary role in cost recovery from these activities. Consequently, revenue from SWM projects is channeled to the IMC, not SCM. Additionally, SCM lacks enforcement authority to collect funds or user fees directly from waste generators or to levy royalties from private entities. This limitation can lay potential ground for conflicts and further fragment the roles and responsibilities among involved institutions.

iv) PPPs with caution: Encouraging source segregation and improving the quality of waste in the city are essential strategies for creating a favorable environment for private investments in waste management. While PPPs can be beneficial, they must be approached with caution. ULBs should effectively monitor and regulate private entities to ensure compliance with environmental and labor laws in waste treatment and disposal. Private entities in SWM can sometimes gain excessive influence, leaving ULBs vulnerable and susceptible to pressure tactics, such as threats to halt plant operations. To address this, ULBs should foster competition by attracting multiple private players and enhance their capacity to carefully evaluate and select private agencies for SWM projects.

4.2 Decentralized Bio methanation plant in Ujjain smart city

4.2.1 Ujjain: City Profile

Ujjain smart city, one of India's ancient cities, is located in the central Indian state of Madhya Pradesh. With a geographical expanse of approximately 92.68 square kilometers (See Figure 25), it has a population of 5.1 lakhs. Ujjain holds historical, religious, and cultural significance. Known for its rich heritage, the city is positioned on the eastern bank of the Shipra River and serves as a vital cultural and spiritual hub in the Malwa region. The city is divided into 54 wards and 6 zones.

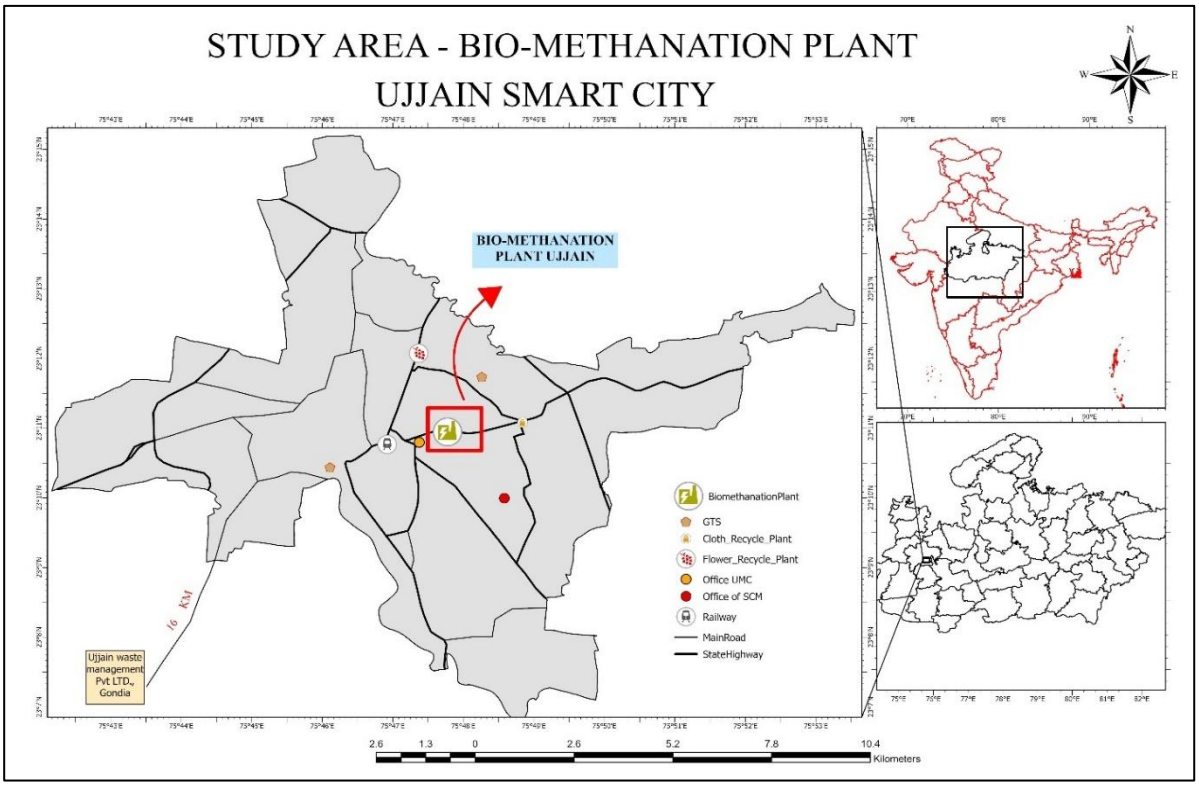


Figure 25:Study area: Ujjain municipal boundary with locations of SWM facilities
Source: Authors

4.2.2 MSWM in Ujjain

Ujjain was selected as the cleanest medium city in Swachh Survekshan Survey, 2019. The city generates 220-250 TPD waste with a per capita waste generation of 0.5 kg/day. The city claims to have 100% door to door collection and 95% of segregation at source. There are 135 vehicles with UMC, of which 91 vehicles (tippers) are used every day for door to door collection and transportation. The collected waste from households, commercial establishments and public bins are transported to two Garbage Transfer Stations, where secondary segregation is performed manually. The waste is further transported to the Gondia plant, which is located in a village outside the city, where there is a composting and landfilling facility. The compost is sold to fertilizer companies. The dry waste is converted to Refuse Derived Fuel (RDF) and transported to cement industries for co-processing as

fuels. While the wet waste is managed effectively, further segregation of dry waste for recycling purposes is lacking. Recycling is more sustainable than converting waste to Refuse-Derived Fuel (RDF) as per the waste hierarchy.

The city also has three decentralized initiatives including i) a bio-methanation plant that treats the wet waste produced in the vegetable markets and few bulk waste generators ii) a flower processing unit that creates Agarbattis out of flower waste coming from the famous Mahakaleshwar temple in Ujjain and iii) cloth and paper processing units, where people dispose off their cloth waste voluntarily and it is processed to generate paper products. MSWM in Ujjain is summarized in Figure 26.

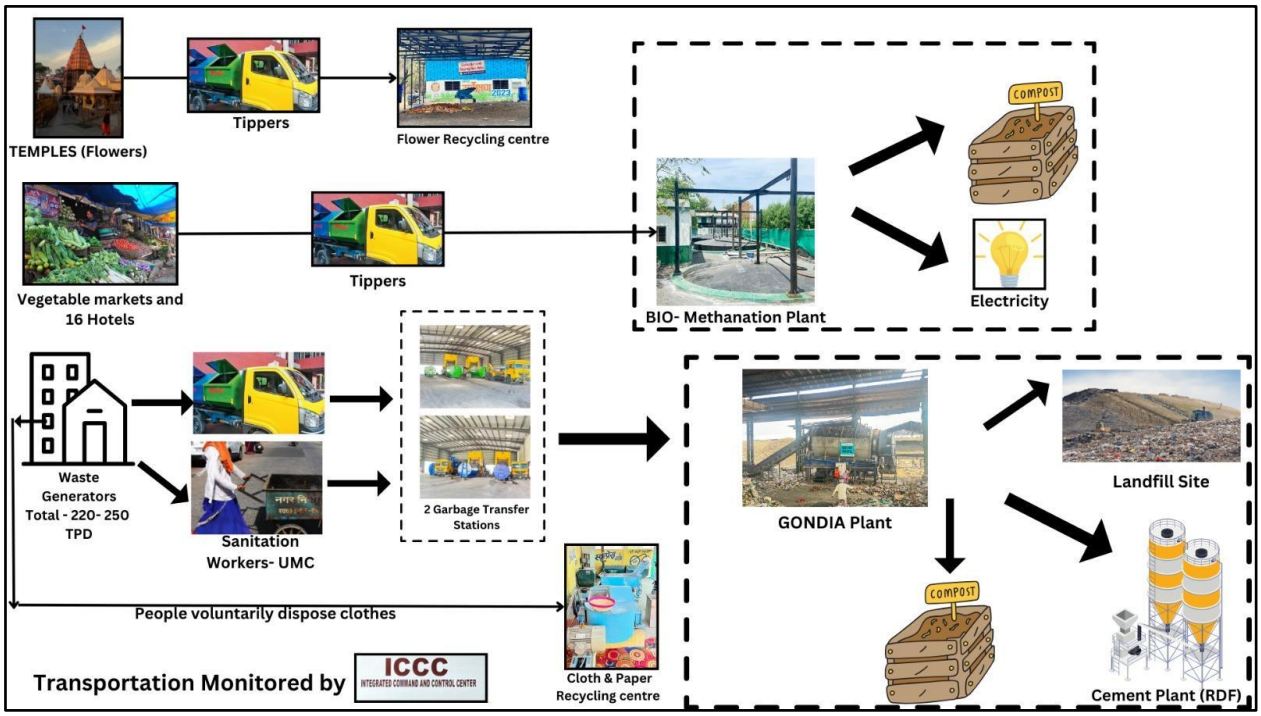


Figure 26: MSWM in Ujjain

Source: Authors

Decentralized Bio methanation plant in Ujjain

The SCM Ujjain has implemented a decentralized bio methanation plant (See Figure 27) with a 5-ton-per-day (TPD) capacity. This facility was designed to treat wet waste from the city's vegetable markets and 16 restaurants, generating 150 kWh of electricity per day. The electricity produced was connected to the Madhya Pradesh Electricity Board (MPEB) grid and used for street lighting, providing a local solution for organic waste management. The waste to energy process is detailed in figure 28. This initiative was intended to divert waste from the centralized facility, thus reducing the transportation emissions and costs and reducing the tipping fees involved. It represented an approach to selecting appropriate technology based on the quantity and characteristics of the waste, as well as the generation and utilization of biogas, offering a sustainable decentralized solution within the community rather than shifting the burden to the city outskirts.



Figure 27: 5 TPD Bio methanation plant in Ujjain

Source: Authors during field visit

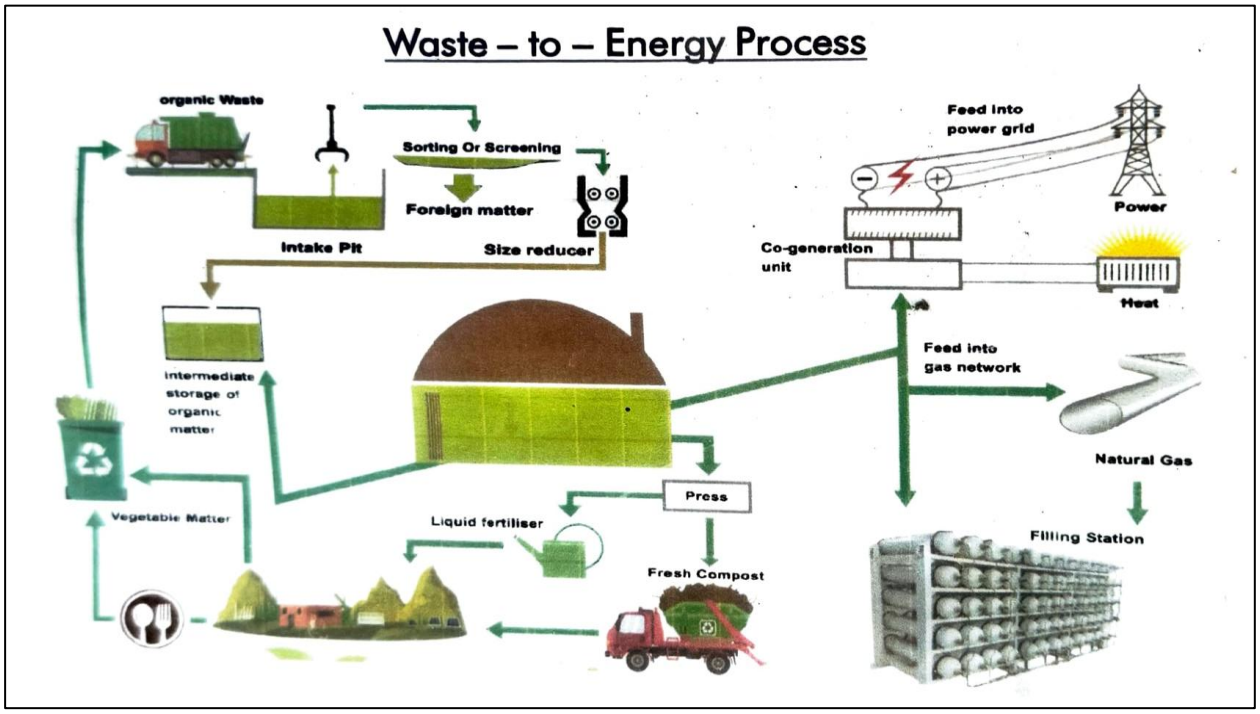


Figure 28: Waste to energy process involved in bio methanation plant

Source: Plant Manager, Aryan Associates, 2024

The plant aimed to generate green energy, reduce carbon footprints, and raise awareness about clean and green technologies to combat global warming. It received many national and state-level awards for its sustainable approach to curbing waste pollution. However, despite its initial success, the plant

became non-operational since February 2024. The private agency running the plant cited non-payment from the Smart City Mission (SCM) as a critical issue. Additionally, the end of the plant's tender created administrative challenges during the handover from SCM to the Ujjain Municipal Corporation (UMC). The UMC attributed the delay to administrative hurdles, while SCM argued that the private agency lacked technical compliance. The plant being non-operational for months led to maintenance issues such as leaky rooftops (See Figure 29), making its reactivation a challenging task that requires extensive repairs. These issues highlight the complexities involved in the long-term viability of such projects.

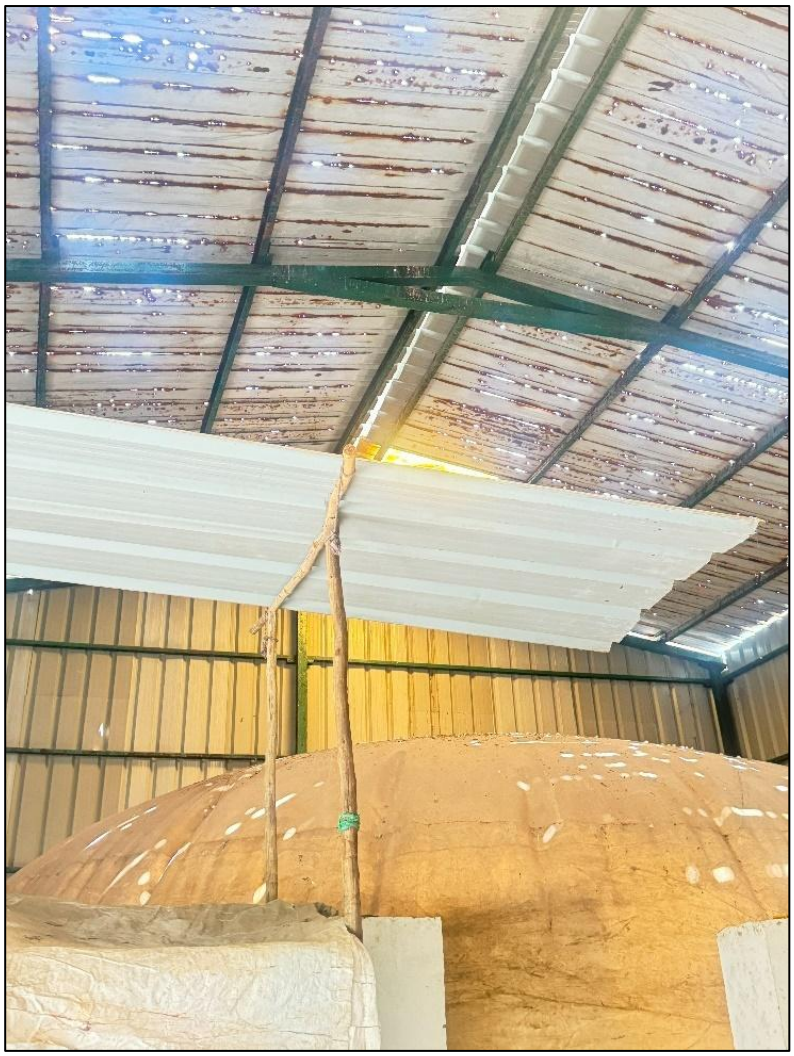


Figure 29: Leaking rooftops due to lack of maintenance after the plant became non-operational

Source: Authors during field visit

4.2.3 Stakeholders involved and the role of Smart City Mission

The direct stakeholders involved in the functioning of the plant are the Smart City Mission (SCM), Aryan Associates (the private agency), the Ujjain Municipal Corporation (UMC), and the waste generators. Installed and operated under a Public-Private Partnership (PPP) model by SCM in collaboration with Aryan Associates, the plant received a capital investment of INR 1.14 crore from SCM, with an additional INR 0.79 crore allocated for operation and maintenance over a five-year period from 2019 to 2024, totaling INR 1.95 crore. During this period, Aryan Associates handled the plant's operation and maintenance. The revenue generated from the electricity, sold at INR 6 per unit, contributes to an annual cost recovery of INR 3,28,500 in SWM for UMC, which also received the compost produced by the plant. After five years, the project was gradually handed over to the UMC, marking the withdrawal of the SCM. However, the handover process was not smooth. The plant is financially non-viable, with annual operation and maintenance costs exceeding revenue generation. Without the capacity or resources to absorb these financial burdens, the ULB is unable to sustain the plant, resulting in its eventual closure.

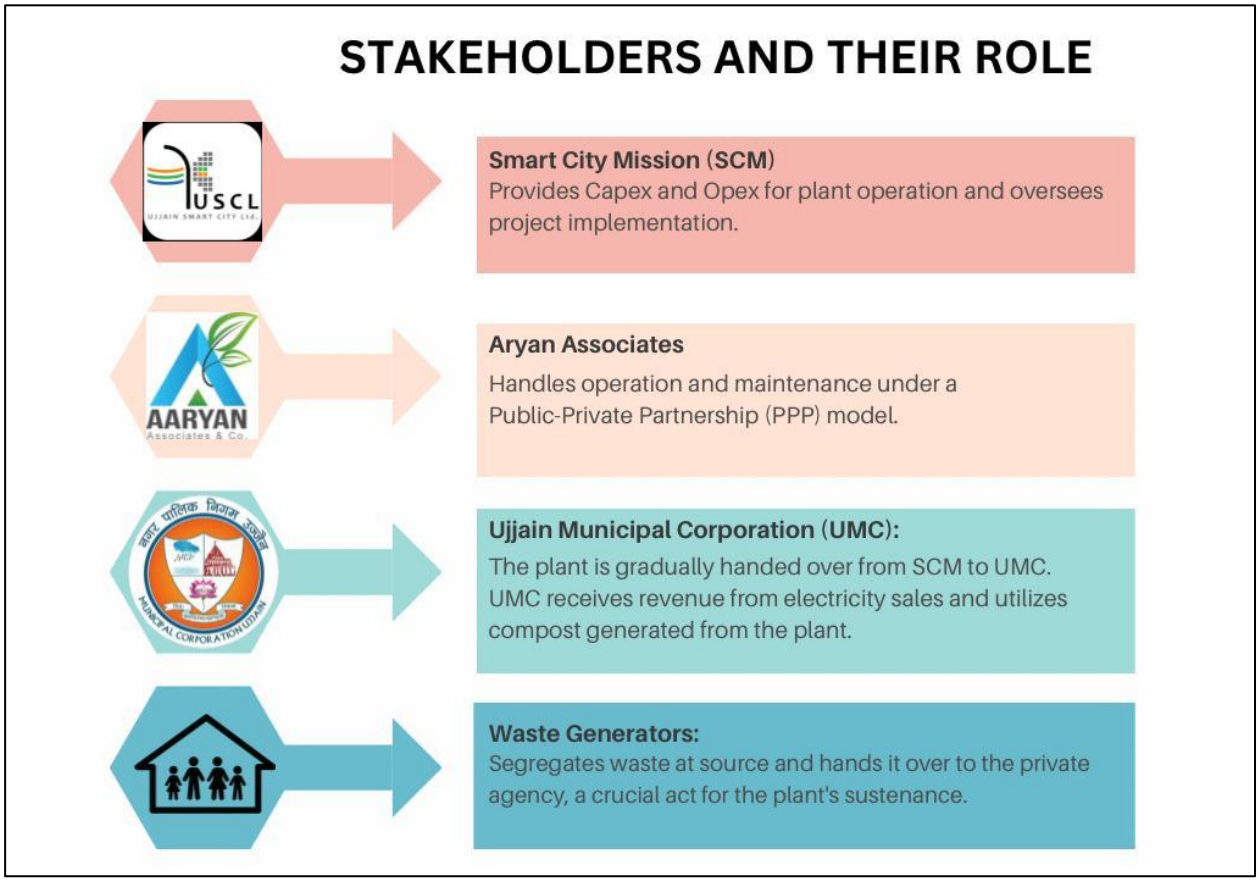


Figure 30: Stakeholders and their role in Ujjain bio methanation plant

4.2.4 Impacts

Environmental impacts

Table 4 shows the different types of annual GHG emission reductions involved when the plant was operational.

Green House Gas emissions

i) By generating electricity from waste, replacing coal, the plant contributed to net annual GHG emission reduction of 0.12 tons CO_2[12].

ii) Being a decentralized facility, it diverted 5 tons of waste from the centralized facility everyday by reducing annual GHG emissions of i) 1911 tons CO_2 eq. by prevention of MSW landfilling[13] and) 85.10 tons of CO_2 eq. by reducing the transportation emissions[14].

iii) The net GHG emission reduction is found to be positive with 1977.2 tones of CO_2 eq. per year.

iv) The compost generated by the bio methanation plant, 0.2 TPD, is used in the gardens managed by the Ujjain Municipal Corporation (UMC) as a soil conditioner. However, the impact of the compost remains difficult to quantify due to the absence of data on its quantity and composition.

Table 4: Annual GHG emission reduction due to the Ujjain Bio-methanation plant while it was operataional

Type of emissions	Annual emissions in tones CO_2 eq.)
Direct emissions during the process of waste to energy conversion	-1.82
MSW diversion	1911
Electricity generation	0.12
Reduction in transportation emissions	85.10
Transportation of waste to plant	-6.85
Electricity consumption at the plant	-10.35
NET GHG emission reduction	1977.2

[12] Average electricity generated at the plant from waste = 150 kWh/day. Average coal based electricity consumed at the plant= 35 kWh/day. GHG emission reduction by coal replacement was calculated considering a grid emission factor of 0.81 t CO_2 eq per 1 MWh coal-based electricity generation (CEA, 2014).

[13] Calculated using IPCC GHG inventories and methane commitment model.

[14] Emission factor for diesel = 2.68 per litre (IPCC, 2006; Patel et al., 2023). Diesel consumption per day for door to door collection and transportation of 250 tonnes of waste to centralized treatment facility at Gondia village, Ujjain = 4350 liters (UMC, 2024). Diesel consumption per day for transportation of 5 tonnes waste= 85 liters (UMC, 2024).

Economic impacts

i) Saved annual tipping fees of around 11 lakhs for the Ujjain Municipal Corporation (UMC).
ii) Revenue from electricity added up to an average annual cost recovery of INR 3.3 lakhs for UMC[15].
iii) Being a decentralized intervention, approximate annual collection and transportation cost savings was INR 26 lakhs for UMC[16].
iv) Life cycle cost analysis shows that the plant could become profitable if it sustained its operation for at least 7 years and if indirect benefits were included in the financial viability assessments like tipping fee reduction and transportation cost reduction (cash flow diagrams and calculations attached in Appendix 1. During the operational period, the ULB could generate an annual revenue of 40.4 lakhs in the form of i) tipping fee reduction ii) electricity sale and iii) transportation cost reduction. However, after five years it had a viability gap of INR 16.7 lakhs. When the indirect benefits are not included, the plant is under loss with annual O&M cost (0.16 Crores) exceeding the revenue from sale of electricity (0.033 Crores) and a net present value of -1.62 crores.

Social impacts

i) The establishment of the bio methanation plant had generated 7-8 jobs within the facility, contributing to local employment. However, since the plant became non-operational, workers had to find other employment opportunities.
ii) Social acceptance – Initially, there was reluctance among people regarding the waste management facility situated in their locality (in market area), driven by concerns over loss of land and affecting their business. However, as the facility began effectively managing waste and improving the cleanliness of the area, social acceptance grew significantly.
iii) The decentralized waste management system, strategically located within the city centre rather than on its outskirts, ensures a more equitable distribution of both benefits and burdens within the community. This approach reduces the environmental and social disadvantages typically borne by peripheral communities, fostering inclusivity and fairness in urban waste management.
iv) Decentralized waste management systems also facilitate greater community awareness about cleaner and greener waste management practices. Situated in a densely populated area, the plant sends a strong message about responsible waste disposal and environmental stewardship, encouraging people to adopt more conscientious waste management behaviors.
v) Community participation is commendable, as the waste generators actively segregated waste at the source, contributing to the efficiency of the plant, while it was operational.

[15] The plant generates an average of 150 kWh electricity every day, sold at INR 6/unit.

[16] Diesel consumption per day for door to door collection and transportation of 250 tonnes of waste to centralized treatment facility at Gondia village, Ujjain = 4350 liters (UMC, 2024). Diesel consumption per day for transportation of 5 tonnes waste= 85 liters. Diesel consumption per day for collection and transportation of 5 tonnes waste to biomethanation plant = 7 liters (UMC, 2024). Total fuel saved= 78 liters everyday. Approx. cost per liter of diesel = INR 90.

4.2.5 Success factors

Even though the plant couldn't sustain in the longer run, it functioned effectively for five years. Below listed are the factors that contributed to its initial success.

i) **Decentralized approach:** The approach focused on selecting appropriate technology based on the waste quantity and characteristics, as well as the generation and utilization of biogas, providing a sustainable solution within the community. This approach avoids shifting the waste management burden to the city outskirts, thereby ensuring that the intervention was integrated into the local context and visible to the community it served.

ii) **Availability of source segregated waste:** Source-segregated waste is more readily available from vegetable markets and bulk waste generators such as restaurants compared to household waste, both in terms of the required quantity and quality.

iii) Technical innovations

- **Net Metering Grid Connection:** Integration of an anti-islanding sensor ensuring safety by automatically halting the plant's electricity supply during main grid faults, preventing potential dangers such as blasts.
- **Frequency Synchronization:** Installation of a French-designed frequency synchronization panel and an auto-phase synchronization panel enabling safe and efficient matching of variable generator frequencies with the static grid frequency, enhancing operational safety and reliability.

iv) **Timely disbursal of funds from smart city mission:** limited to the initial five years for which the plant has successfully operated.

4.2.6 Challenges

i) **Waste Characteristics and Seasonal Variations**: Biogas technology is sensitive to the composition of its feedstock. Presence of organic waste components like drumsticks, lemon peels, and coriander leaves obstruct the digester. Additionally, seasonal variations pose a significant challenge; during the monsoon season, the waste has a lower calorific value, which prolongs the gas production process and reduces electricity output.

ii) **Land Availability Within the Community:** Securing land for the plant within the densely populated area of the city, rather than on the outskirts, posed significant challenges. Local residents were initially fearful that the plant might encroach upon their space, leading to resistance. To address these concerns, the UMC undertook extensive awareness campaigns and effectively communicated the benefits and importance of the plant to the community, which facilitated the integration of the plant within the urban setting. However, scaling up such interventions remains difficult due to the major constraint of land availability in urban areas, making it challenging to replicate this model elsewhere.

iii) **Need for participatory planning**: Effective governance in SCM projects is hampered by a lack of collaboration and integration among various stakeholders. While quick decision-making devoid of political interference is often seen as a favorable condition for SCM, this approach may not support the long-term sustainability of interventions, particularly in the SWM sector. Long-term sustenance requires socio-political engagement, and SCM projects inevitably need to be transitioned to ULBs. Therefore, a participatory approach involving all stakeholders from the planning stage to execution is essential. Smooth handovers to departments are often problematic, leading to projects that end up as mere assets rather than sustained initiatives. This highlights the necessity for strong institutional mechanisms and participatory planning to ensure these projects do not falter post-implementation. Furthermore, ULBs often struggle with funding and resource allocation, underscoring the need for effective collaboration and planning from the outset.

iv) **Challenges with Compost Production**: The compost generated by the plant, while used as a soil conditioner in UMC gardens, does not contribute to revenue generation due to the absence of a structured quality control mechanism and market strategy.

v) **Challenges with Revenue Generation through user fees**: Despite the presence of large-scale waste generators, such as vegetable markets and restaurants, there is no user fee collection mechanism in place for these entities. This lack of user fee collection from bulk waste generators (BWGs) results in a missed opportunity for additional revenue that could support the plant's operational costs. Moreover, without this financial contribution, the economic sustainability of the waste management system is compromised, relying heavily on municipal funds or external subsidies.

4.3 Case 3: Mass incineration plant in Jabalpur smart city

4.3.1 Jabalpur: City profile

Jabalpur smart City is the cultural capital of Madhya Pradesh located in the Eastern part of the state, on the banks of river Narmada. The city has an approximate population of 12.6 lakhs and is the country's 38th largest agglomeration (Census, 2011). It is one of the major industrial and business centers of Madhya Pradesh. The city covers an area of 263 sq. km and is administered by Jabalpur Municipal Corporation (JMC) (Figure 31).

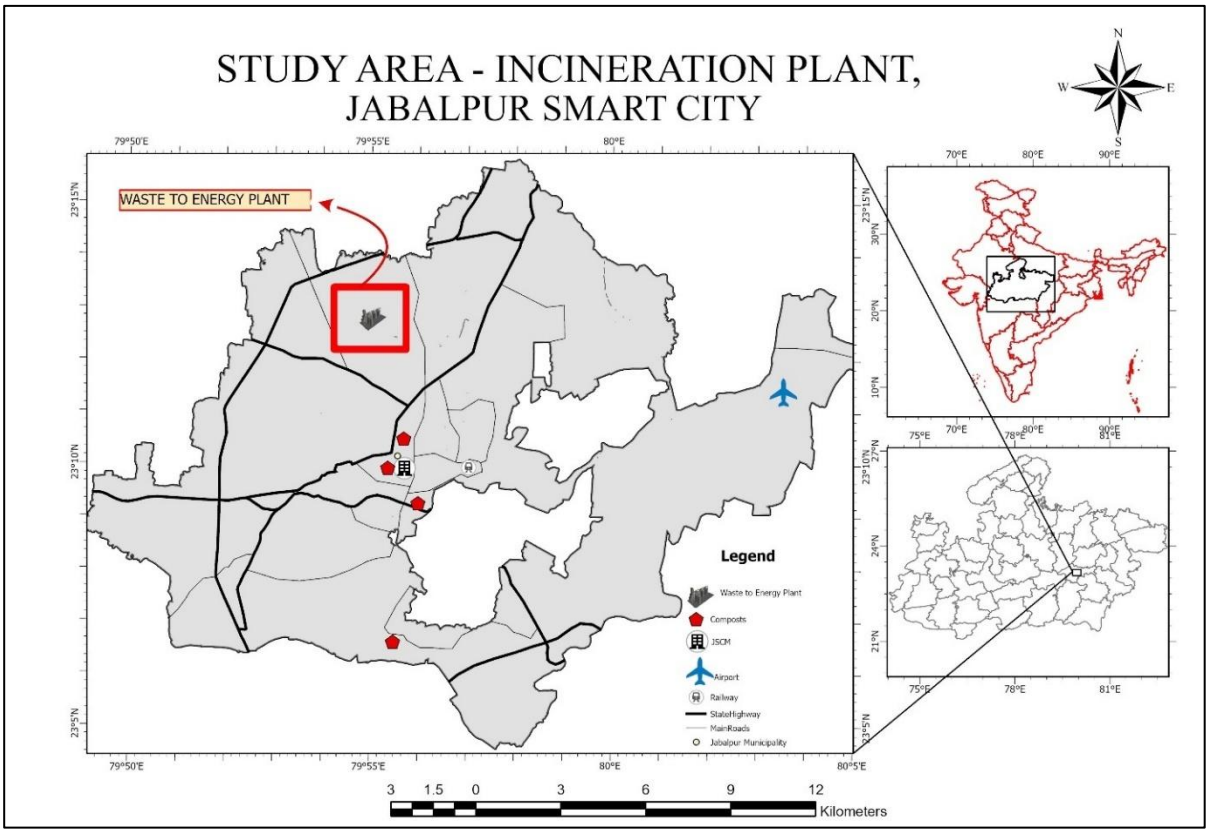


Figure 31: Study area: Jabalpur municipal boundary with locations of SWM facilities

4.3.2 MSWM in Jabalpur

MSWM in Jabalpur has significantly changed from its earlier practices. Previously, waste was unscientifically disposed of at two primary sites: the Ranital dump yard (18 acres) in the city center and the Kathonda dump yard on the outskirts. Littering and open burning was prevalent. Over the period, with the help of NGOs, awareness campaigns were conducted to prevent littering and handover the waste to JMC. The Ranital site (10 acres) was later remediated through a biomining process funded by the Smart City Mission. Further, the Jabalpur Municipal Corporation (JMC) constructed a scientific landfill at the Kathonda location. In 2016, a waste-to-energy plant based on mass incineration was established at the Kathonda landfill site by Essel Infra in PPP mode with JMC, that treat the mixed waste generated in the city.

Currently, Jabalpur generates approximately 550 tonnes per day (TPD) of municipal solid waste (MSW), with a per capita generation of 460 grams per day. JMC and a private agency does the door to door collection of mixed waste and transport it to the centralized WTE facility, where the waste is incinerated to generate electricity. Jabalpur's waste-to-energy plant, located at the Kathonda village, with a capacity of 600 tonnes per day (TPD), treats an average of 500 TPD of municipal solid waste (MSW) and generates 11.5 megawatts (MW) of electricity. Of the total waste, 94% is treated at the centralized mass incineration-based waste-to-energy plant. The remaining 6%, constituting 35 TPD of wet waste, is processed into compost at decentralized facilities and sold in the local market (See Figure 32).The MSWM in Jabalpur is summarized in figure 33.

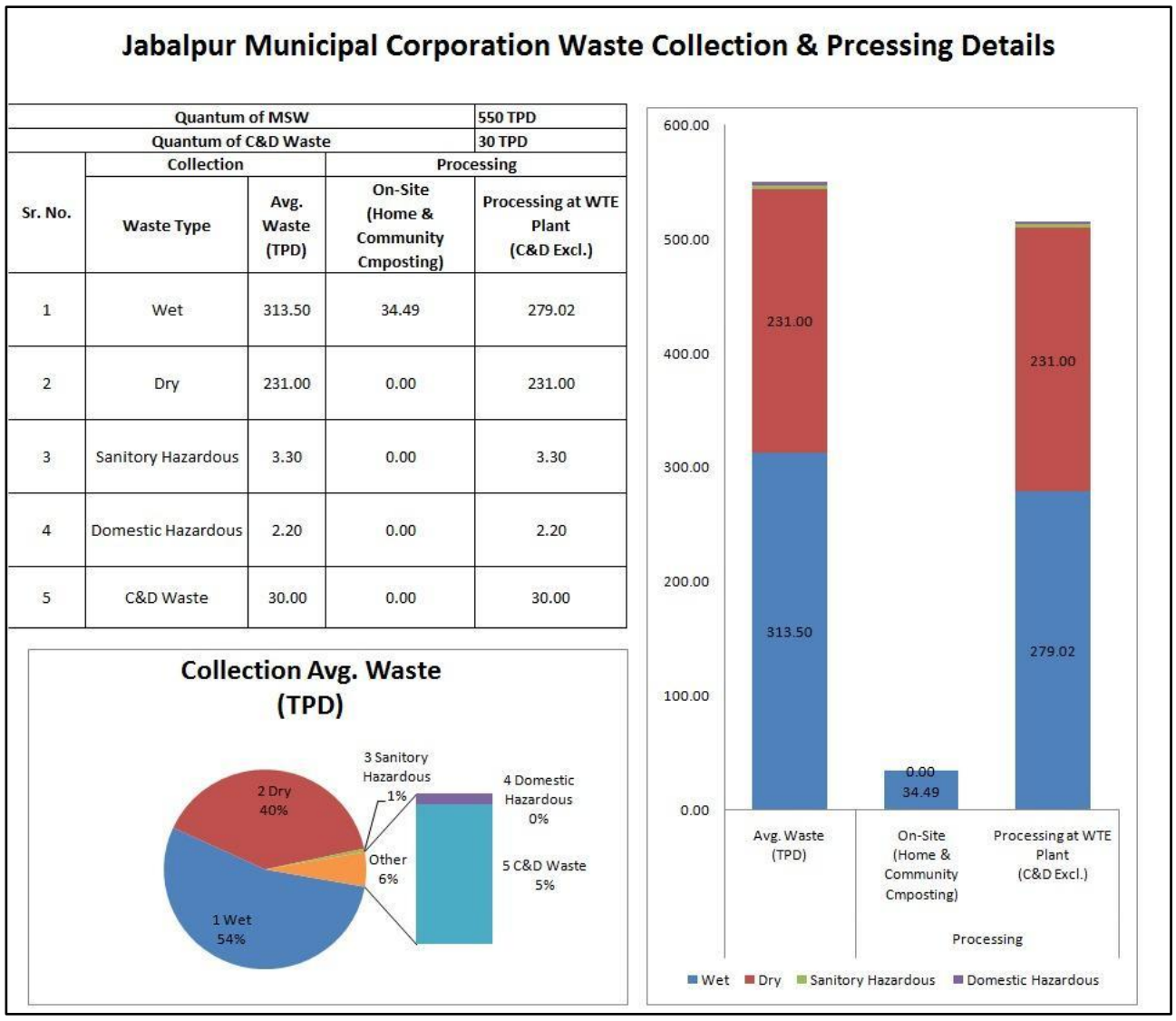


Figure 32 Waste collection and processing details of JMC

Source: Swachhata cell, Jabalpur

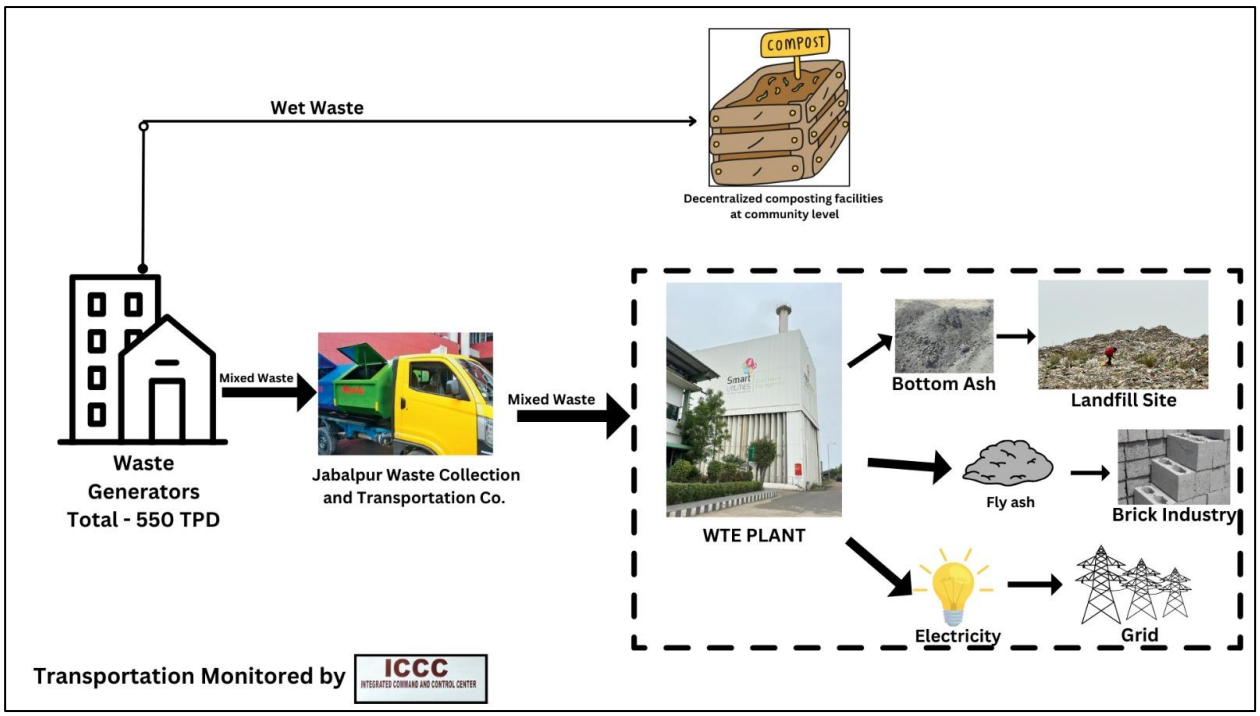


Figure 33: MSWM in Jabalpur Municipal Corporation
Source: Authors

4.3.3 Centralized mass incineration based WTE plant in Jabalpur

The process of conversion of waste to electricity is detailed in Figure 34. The treatment process begins with the waste being deposited into a waste pit. From the pit, a grab crane mechanically segregates the waste, removing large objects such as stones, construction debris, and inert materials. The remaining MSW is then transferred to a feed hopper and subsequently fed into a furnace for mass combustion. The resulting flue gas passes through an Air Pollution Control (APC) unit and treated wastewater passes through an effluent treatment plant.

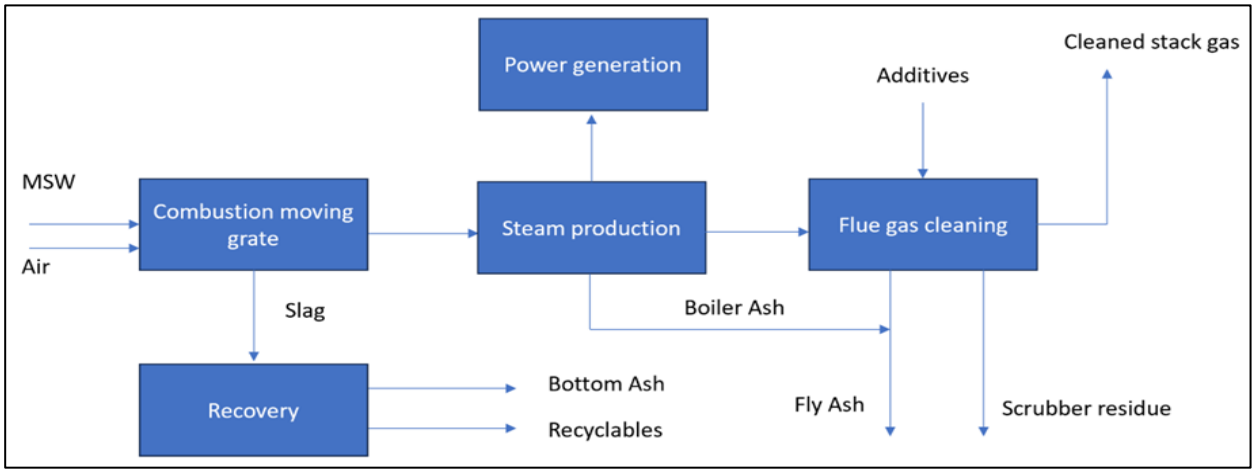
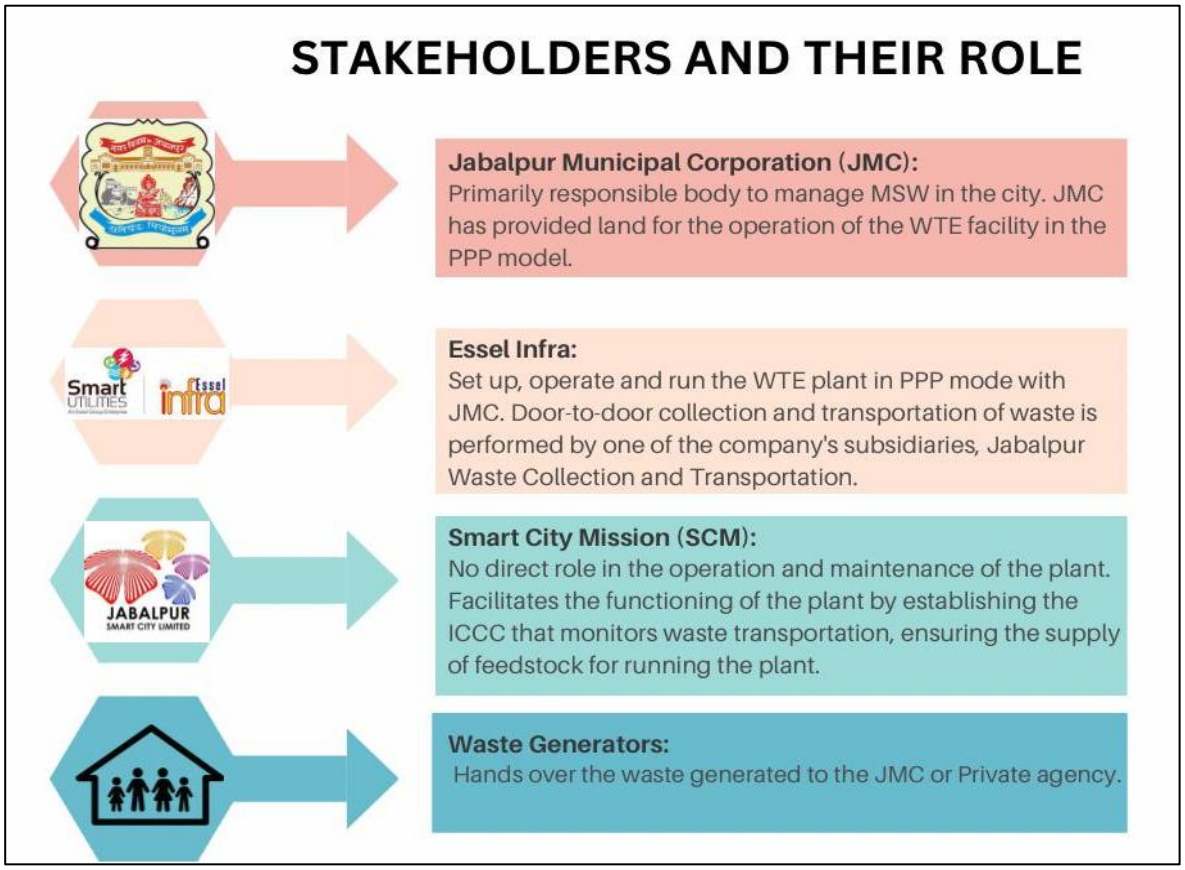


Figure 34: Waste to energy conversion process in mass incineration plant, Jabalpur
Source: Detailed project report

4.3.4 Stakeholders involved and Role of SCM

The direct stakeholders involved in the functioning of WTE plant are: Jabalpur Municipal Corporation, Implementation Agency- ESSEL Infra and Vendor on board for Garbage Collection– ESSEL Infra (Figure 35). It is fundamentally a project of Jabalpur Municipal Corporation (JMC), having been planned and initiated before the city was selected under the Smart City Mission (SCM). Although the SCM often showcases the WTE plant as a part of its initiatives, it plays no direct role in its operations or decision-making processes. However, the SCM does contribute indirectly by enhancing the efficiency and monitoring of the waste management system. This includes the removal of legacy waste and the implementation of transportation monitoring via the Integrated Command and Control Center (ICCC). The ICCC utilizes RFID technologies to streamline waste collection and transportation, thereby facilitating the effective operation of the WTE plant.



4.3.5 Impacts

Environmental

Green House Gas emissions

Table 5 shows the different types of annual GHG emission reductions involved when the plant was operational.

Table 5: Annual GHG emission reduction due to the Jabalpur mass incineration plant

Type of emissions	Annual emissions in tones CO_2 eq.)
Direct emissions during the process of waste to energy conversion[17]	-2720327294
MSW diversion	242526
Electricity generation	80783
Fly ash reutilization	3811
Transportation of waste to plant	-4.8
Electricity consumption at the plant	-3091
NET GHG emission reduction	-2720003270

i) While incineration reduces some GHG emissions by diverting MSW from landfills (in this case 2.4 lakh tonnes of CO_2 eq. annually) and generating electricity (80783 tonnes of CO_2 eq. annually) that replaces conventional energy sources, its direct emissions during operations are significantly high (272 million tonnes of CO_2 eq.). This results in a net increase in GHG emissions, making incineration neither a truly green nor renewable energy source. Therefore, electricity generation by incineration of waste does not contribute in terms of replacing fossil fuels. It can reduce some GHG emissions, only when it is used as an alternative to open dumping, open burning and sanitary landfills.

ii) The **fly ash**[18] which is a byproduct of incineration produced in the plant **is recycled in a nearby brick industry**. This is commendable as it helps reduce environmental impacts associated with waste disposal. Fly ash contains various pollutants and heavy metals that, if not managed properly, can leach into the environment, contaminating soil and water sources. This practice also reduces the volume of waste going to landfills, thereby conserving landfill space and mitigating potential pollution risks.

Pollutant emissions to air

The plant has an Air Pollution Control (APC) unit to manage stack emissions and reduce air pollution. However, **transparency and monitoring of these emissions pose significant concerns.** The Madhya Pradesh Pollution Control Board (MPPCB) is tasked with real-time monitoring, but data availability on their website is limited. As of 2021 and 2022, **emissions data was only available for 29% and 23% of the time respectively, despite the plant operating since 2016.** The plant operator has cited technical issues with the transmitter responsible for transmitting emissions data to the CPCB, attributing delays in replacements to the involvement of overseas suppliers. Further, t**he parameters monitored—nitrates, sulfates, and particulate matter—do not encompass emissions of other harmful substances like hydrogen chloride, hydrogen fluoride, dioxins, furans, and heavy metals (mercury, cadmium, lead, and copper)**.

[17] Calculated using the IPCC GHG inventory and default emission factors.

[18] Approximate fly ash generation in the plant is 160 TPD.

From the available data, of particular concern is the **level of particulate matter emissions**, which **surpass the limits set by the Central Pollution Control Board (CPCB).** In 2021, average emissions were recorded at 54.08 mg/Nm³, and in 2022, at 38.55 mg/Nm³. Maximum values spiked to 230 mg/Nm³ in 2021 and 879 mg/Nm³ in 2022, significantly exceeding both Indian standards (50 mg/Nm³) and the higher European standards (10 mg/Nm³) that were initially proposed in the project's Detailed Project Report (DPR) (Figure 35). Similar observations of exceeding particulates matter limits were found in stack emissions data collected from the plant of February 2024 (Figure 36). However, sulphates and nitrates are found to be within the limits. The inadequate monitoring and enforcement highlight critical gaps in ensuring environmental compliance, emphasizing the need for stricter regulatory oversight and transparency measures.

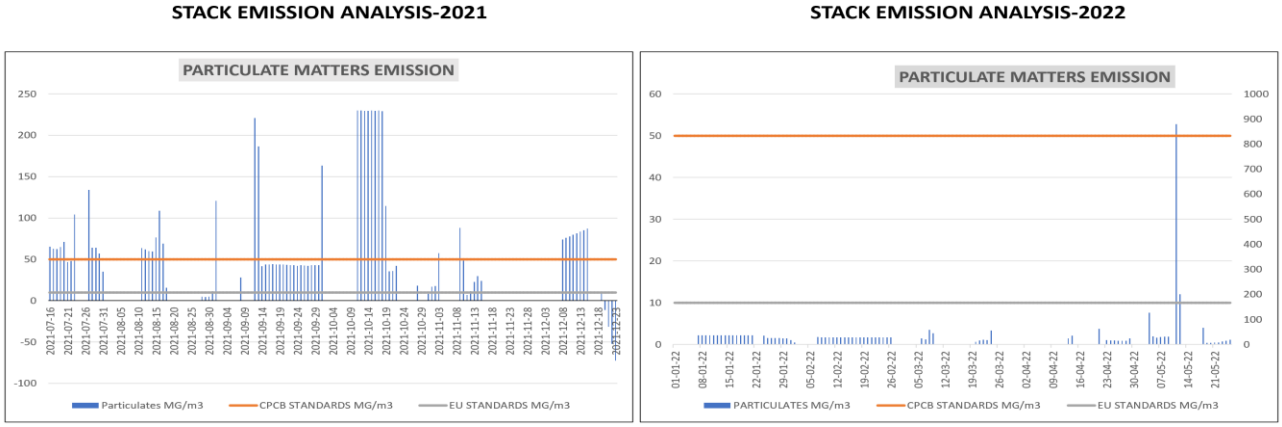


Figure 35: Stack emission analysis from MPPCB website

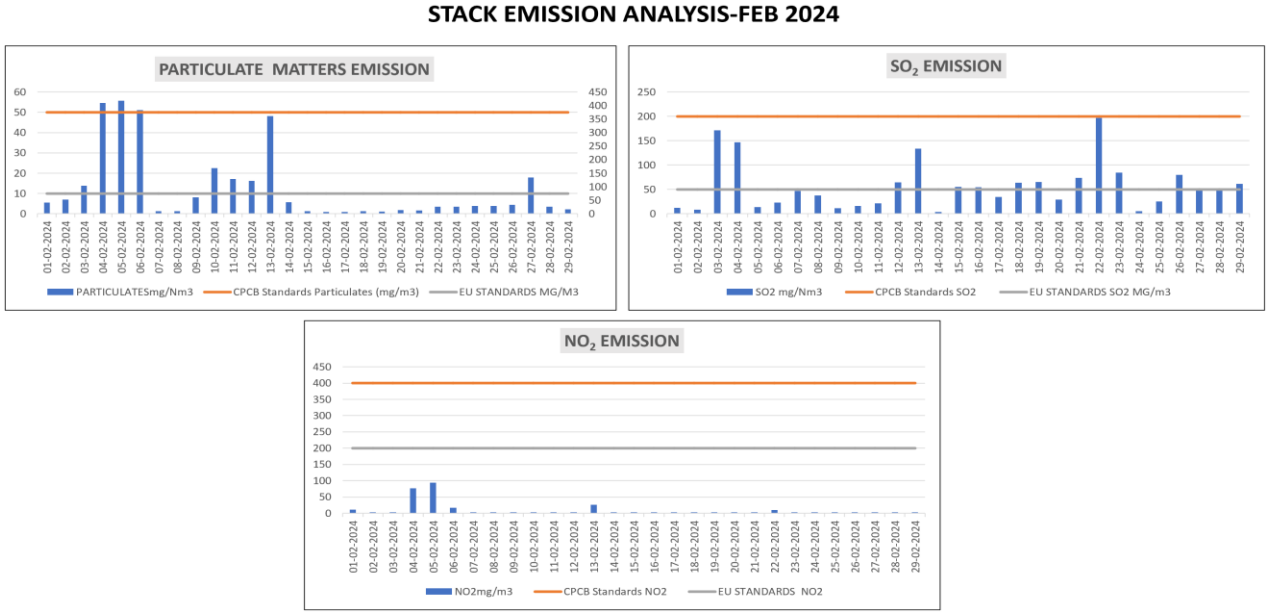


Figure 36: Stack emission analysis from the plant -Feb 2024

The stack emission data collected from the plant for the month of February 2024 also shows spikes in the particulates matter emissions, while SO_2 and NO_2 remains within the limits.

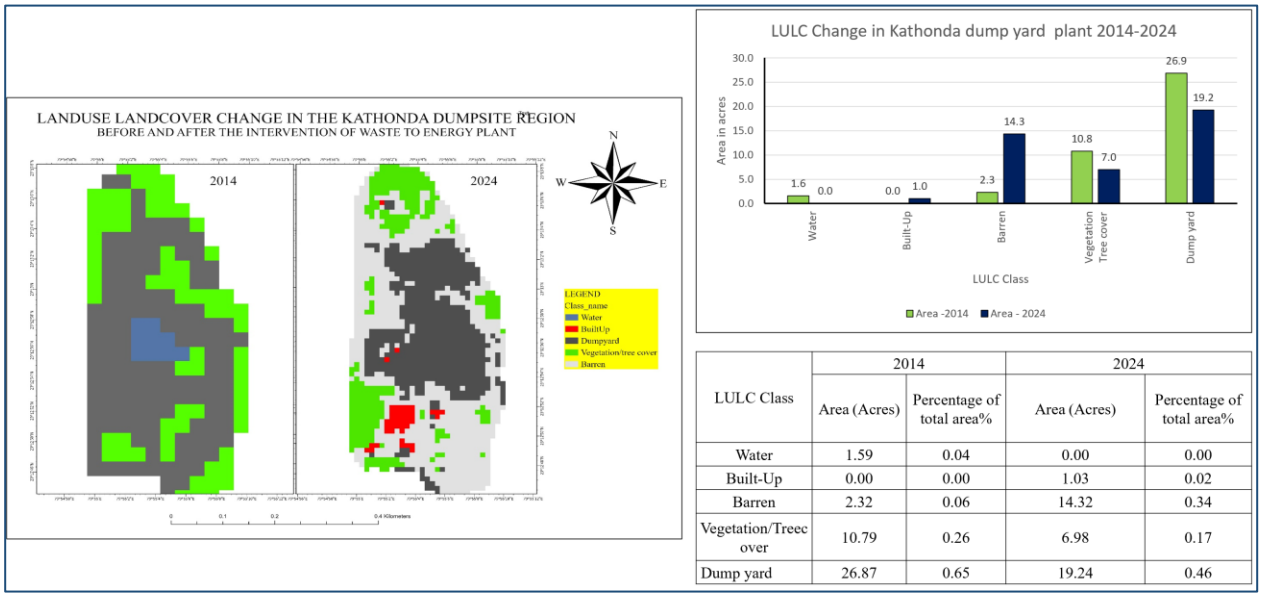
Incineration is indeed preferable to open burning as it confines the combustion process to a controlled environment, reducing the immediate health and environmental hazards associated with open burning. However, the effectiveness of incineration heavily depends on the control and management of stack emissions. If stack emissions are not adequately controlled through proper air pollution control measures, the benefits of controlled burning can be offset.

No pollutant emissions to water

i) The weighted average water quality index of borewells within 1 km of the plant falls within the "Average" category, with values of 58.3 in 2018, 53.4 in 2019, and 54.4 in 2021. These figures indicate minimal impact from the plant on the surrounding water quality. A leachate collection tank is functioning at the plant, ensuring that waste is appropriately treated before release. However, there is currently no available data regarding the quality of the released water.

Land Use Land Cover Change around WTE plant

The land use and land cover change analysis (Figure 37) shows that approximately 7.6 acres of dump yard area has been reduced due to the plant, which is considered moderate but not substantial compared to Indore. While waste-to-energy facilities are expected to contribute to dump yard clearance, the impact in Jabalpur has been limited despite the plant being operational since 2016. This limitation stems from the plant functioning as a standalone facility without waste segregation at the source, resulting in mixed waste being sent for treatment. Additionally, the tipping fee model incentivizes the quantity of waste disposed of rather than its quality. This allows the private agency responsible for waste collection and transportation to maximize profits by sending larger volumes of waste, leading to substantial residual waste. Furthermore, bottom ash, which constitutes approximately one-third of the treated waste, requires additional disposal land making dump yard reclamation practically difficult.



LULC Class	2014		2024	
	Area (Acres)	Percentage of total area%	Area (Acres)	Percentage of total area%
Water	1.59	0.04	0.00	0.00
Built-Up	0.00	0.00	1.03	0.02
Barren	2.32	0.06	14.32	0.34
Vegetation/Treec over	10.79	0.26	6.98	0.17
Dump yard	26.87	0.65	19.24	0.46

Figure 37: Land use land cover change in the Kathonda dumpyard before and after the intervention of WTE plant

Economic impacts

Plant currently under threat due to financial challenges: Commissioned in 2016, the plant was established through a PPP between JMC and Essel Infra. JMC provided the land on a lease basis, while Essel Infra undertook the entire capital expenditure of INR 178 crore, financed through loans from the State Bank of India (SBI). Essel Infra was also responsible for the plant's operational expenditure. Despite the substantial investment, the plant faced significant financial and operational challenges. Initially, the revenue generated was insufficient to cover the loan repayments to SBI. This revenue shortfall was due to the lack of sufficient waste supply from Jabalpur alone, as the city lacked door-to-door collection facilities, and the plant required a minimum quantity of combustible waste to operate effectively. To meet its waste requirements, the plant had to source waste from other cities, including distant locations such as Nagpur and Lucknow. This waste procurement was not free of cost; Essel Infra had to purchase it, adding to the operational expenses. The need to buy and transport waste from other cities further strained the plant's financial viability and operational efficiency. Ultimately, the combination of insufficient local waste supply, the costs associated with acquiring waste from other cities, and the financial burden of loan repayments led to challenges in financial feasibility. The plant is currently under court action by the National Company Law Tribunal (NCLT). Following an order from NCLT, all revenue generated by the plant is directed to SBI for cost recovery. SBI provides only a minimal amount to Essel Infra to cover the plant's operational costs and salaries. Thus, although the plant operates under the name of Essel Infra, its financial management and revenue allocation are controlled by the bank.

Essel Infra is withdrawing from managing the plant due to administrative reasons, as they find their other business ventures more profitable than the waste sector. The current plan is to transfer the operation and maintenance (O&M) of the plant to another private entity. However, potential operators are hesitant to take on the initiative due to concerns about its financial viability. In such a scenario, Urban Local Bodies (ULBs) are likely to face significant challenges, as they lack the capacity and resources to effectively operate and maintain the plant on their own. In short, the Jabalpur waste-to-energy plant illustrates the economic challenges of waste management projects, highlighting the critical need for sustainable operational models.

Social impacts

i) **Job Creation at the Plant:** The plant has created employment opportunities for approximately 75 skilled workers, offering regular salaries and social security benefits. Most of these workers are sourced from within Jabalpur, contributing to local employment generation.

ii) **Unintegrated Informal Waste Sector:** During our field visit, we observed many children engaged in waste picking at the dump yard near the plant area (see Figure 38). It was reported to us that women, children, and elderly individuals have been scavenging recyclables from this area even

before the plant's inception. This indicates that many of them lost their livelihoods when the plant began operations, as the plant requires combustibles that are also recyclable and provided income to waste pickers. However, waste picking still persists, exposing them to hazardous conditions and limiting their access to education and healthcare. Their rehabilitation or integration into the formal system is essential to ensure an inclusive SWM system in Jabalpur.



Figure 38: Waste picking children in dump yard near WTE plant, Jabalpur

Source: Authors during field visit

iii) **Lack of social acceptance:** Social acceptance of the plant is minimal, as reflected in many negative media reports. These reports highlight public concerns and dissatisfaction, undermining support for the facility.

iv) **Lack of community participation** – The plant processes mixed waste, which is not a sustainable option in the long term. Effective waste management requires community participation, particularly in segregating waste at the source. Jabalpur must priorities raising awareness and implementing source segregation initiatives. Without these efforts, transitioning to more sustainable alternatives like composting or bio methanation will be challenging.

v) **Inequitable distribution of benefits and burdens**- The establishment of the WTE facility on the city outskirts allowed for the reclamation of the Ranital dump yard in the city center, benefiting urban residents by improving local conditions. However, this centralized approach highlights an inherent challenge: the burden of waste management is shifted to peripheral areas.

4.3.6 Challenges

i) Lack of segregation at source can hamper long term sustainability of SWM: Since the mass incineration technology promises to treat the mixed waste generated in the city, there are lesser efforts to promote segregation of waste at source. This can hamper the long-term sustainability of SWM in the city of Jabalpur as other resource recovery interventions in future like composting, bio methanation, etc. The plant's reliance on mixed waste, rather than promoting segregation and other Rs (Reduce, Reuse, Recycle), is not aligned with the Solid Waste Management (SWM) Rules 2016 and has resulted in decline in Swachh Survekshan ranking of the city.

ii) Technology lock in: The plant can result in technology lock-in for the city by creating structural, economic, and institutional dependencies that hinder the adoption of more sustainable waste management practices due to the following reasons. a) Significant capital investment of 178 Cr financed through loans and ongoing debt obligations can lock the city into continuing WTE operations, even if other SWM methods become more viable or desirable. b) The long-term contracts in PPPs involve agreements on continuous supply of waste, making it difficult for the ULB to redirect waste streams to any other forms of processing. c) Continuous supply of higher calorific value of waste and waste imports from other cities for meeting the plant's operational requirements complicates transitions to local and decentralized waste management strategies as recommended in SWM rules (2016). iv) A significant institutional and community adaptation would be required to promote segregation and source, to shift to sustainable practices in future.

iii) **Long-term sustainability of the plant is uncertain**: due to existing debt burdens and the impending withdrawal of Essel Infra. Potential private operators are reluctant to take over the plant, citing concerns about its economic feasibility.

iv) **Tipping fee model adversely affects the quality of feedstock:** The current tipping fee model[19] which incentivizes higher waste quantities, poses a significant challenge to the plant's operation. To maximize income, the private agency responsible for waste transportation often includes large quantities of non-combustible waste such as road sweepings mixed with soil. This practice increases the weight and volume of waste but degrades its quality, adversely affecting the plant's efficiency. This approach beyond undermining the plant's operation also highlights a conflict of interest: while economic gains are tied to greater waste volumes, the broader goal of reducing

[19] ULB pays the private agency for transportation of waste - as per the quantity and volume of waste transported and not quality of waste.

waste generation suffers. As a result, efforts to prioritize waste reduction, reuse, and recycling within a circular economy framework are compromised.

v) **Maintenance delays:** There are high maintenance delays **due to the plant's reliance on imported parts**. For instance, critical components, including the transmitter for stack emissions data, are sourced from overseas, leading to prolonged delays in repairs and replacements. This has resulted in substantial gaps in emissions monitoring and reporting to the Pollution Control Board (PCB).

vi) **Lack of collaborative governance:** Conflicts between the stakeholders were noticed, once the plant ran into operational and financial crises. The private operator, Essel Infra, blames the Jabalpur Municipal Corporation (JMC) for failing to supply waste of adequate quality, which hindered efficient plant operation. On the other hand, JMC maintained that they had fulfilled the terms of the agreement by providing the required quantity of waste. They pointed out that the plant was initially claimed to handle mixed waste, and the private operator's later insistence on specific waste quality was contrary to the original agreement. These conflicts over waste quality and operational responsibility reflect a misalignment of expectations, complicating its effective management.

5. Study Outcome and Conclusions

5.1 Impacts of different WTE plants: A comparative assessment

Table 6: Comparative Analysis of Waste Management Technologies: Indore Bio-CNG Plant, Ujjain Bio-Methanation Plant, and Jabalpur Incineration Plant

Pillars	Indicators		Indore Bio-CNG plant	Ujjain Bio-methanation plant	Jabalpur incineration plant
Environmental	GHG emission reductions (in tonnes CO_2 eq.) (normalized to per tonne waste)	Direct emissions	-0.001	-0.001	-14906
		Avoided emissions	1.17	1.09	1.79
		Embodied emissions	-0.03	-0.01	-0.02
		Net GHG emission reduction	1.14	1.1	-14904
	Pollution to air		NA	NA	Particulate matters often exceeding the limit. Lack of transparency in reporting real time data.
	Pollution to water		NA	NA	Water quality within limits in the nearby borewells
	Land recovery		86%	NA	28%
Economic	Capex		150	1.14	178
	Opex		25	0.16	142.4
	Revenue		53	0.033	60.86
	NPV		88	-1.62	-872
	Cost recovery to municipality		9.5%	4.04%	0%
Social and institutional (relative scoring as high, moderate and low)	Social acceptance		Moderate	High	Low
	Job Generation		75	8	100
	Equitable distribution of benefits and burdens within society		Low	High	Low
	Integration of informal waste workers to formal system		High	Moderate	Low
	Community participation in SWM		High	High	Low
	Collaborative governance		Medium	Low	Medium

Environmental Impacts

- **Greenhouse Gas (GHG) Emissions:**
  - Incineration technology in Jabalpur demonstrates significant negative environmental impacts, with high direct emissions resulting in a net GHG emission increase of -14,904 tonnes CO_2 equivalent. While incineration reduces GHG emissions from landfill diversion and generates avoided emissions of 1.79 tonnes CO_2 equivalent per tonne of waste, it remains unsuitable due to its high pollutant levels and unsustainable direct emissions.
  - Bio-methanation plants in Indore and Ujjain, on the other hand, show net GHG reductions of 1.14 and 1.1 tonnes CO_2 equivalent per tonne of waste, respectively. These reductions highlight bio-methanation as a climate-friendly solution, particularly in India, where municipal solid waste (MSW) has a high organic fraction (40–70%).
- **Pollution and Land Recovery:**
  - Incineration plants, like Jabalpur's, face challenges with particulate matter emissions exceeding permissible limits, requiring stringent monitoring and improved transparency.
  - Land recovery is significantly higher for the Indore Bio-CNG plant (86%) compared to Jabalpur's incineration plant (28%), highlighting the importance of an integrated waste management model that reduces the residual waste.
- **Economic viability**
  - Bio-methanation plants have higher CAPEX (₹150 crore in Indore; ₹1.14 crore in Ujjain) and OPEX compared to composting or smaller-scale technologies, but they also generate considerable revenue potential. For instance, the Indore Bio-CNG plant generates ₹53 crore annually, making it economically viable due to economies of scale.
  - Decentralized models like Ujjain's bio-methanation plant face financial viability issues, with lower revenue (₹0.033 crore) and negative Net Present Value (NPV) (₹-1.62 crore).
  - Despite higher revenue generation (₹60.86 crore) in Jabalpur, the incineration plant has an NPV of ₹-872 crore, because of high Capex and Opex further increased by lack of availability of quality feedstock, that has led the plant to financial problems.
- **Social Acceptance:**
  - Indore's Bio-CNG plant enjoys moderate social acceptance due to its significant improvement over previous waste management conditions, while Ujjain's bio-methanation plant has high acceptance due to its decentralized nature and community involvement.

- In contrast, Jabalpur's incineration plant struggles with low social acceptance, compounded by minimal community engagement.

- **Community Participation:**
  - Community participation has been instrumental in the success of Indore's Bio-CNG plant, where effective segregation at the source ensures high-quality input waste.
  - Jabalpur's incineration plant suffers from minimal community participation (in source segregation), which undermines its long-term sustainability.
- **Collaborative governance**
  - In solid waste governance in India, collaborative governance is a crucial factor for the sustainability of any initiative, as multiple institutions are often involved. This creates a potential for institutional fragmentation, overlap of roles and responsibilities, and conflicts among stakeholders. To address these challenges, there is a pressing need for clear guidelines that define the roles and responsibilities of each institution. Additionally, fostering participatory planning processes can help align stakeholder interests, enhance coordination, and ensure the effective implementation and longevity of urban initiatives.
  - In Ujjain, the lack of financial viability and collaborative governance led to the closure of its bio-methanation plant, highlighting the importance of governance over technical capabilities.
- **Equity and Inclusion:**
  - Decentralized models like Ujjain's better distribute the benefits and burdens of waste management, facilitating community stewardship and awareness.
  - Centralized systems, shift the environmental burden to the peripheries, where communities bear the brunt of poor odour and flies and pollution.
  - Indore offers an inclusive model through integration of informal waste workers into the formal system, thereby improving livelihoods and ensuring equitable benefits.

5.2 Technical, economic, environmental and social challenges

The key advantages and critical challenges related to the implementation of each WTE technology is given in Table 7.

Table 7: Key advantages and critical challenges related to implementation of WTE technology

Type of WTE technology	Key advantages	Technical & operational challenges	Environmental Challenges	Economic challenges	Socio-institutional challenges
Incineration	• Better option compared to landfilling or other unscientific practices • Ability to dispose non-recyclable hazardous and mixed wastes	• Lack of availability of quality feedstock with higher calorific value • Auxiliary fuel requirements to run the plant in the absence of quality feedstock • Delays in plant maintenance due to reliance on foreign components	• Lack of stringent emission standards • Lack of transparency in the emissions data • Lack of proper monitoring and enforcements to control emissions • Prevents implementation of waste hierarchy and other sustainable Rs • Bottom ash contains toxic substances and requires effective disposal that consumes land	• High capital and operation and maintenance cost • Increase in operation cost due to Indian waste composition • Electricity generated is expensive compared to other renewable energy sources • Increased burden on public sector due to financial feasibility on procurement of waste at large scale	• Displacement of informal waste pickers by taking hold of whole waste chain in the city • Situation of lock-in: inability to shift to sustainable alternatives • Lack of incentivization or promotion of source segregation discourages public participation and hampers responsible waste management behaviors • Shifting waste burden to outskirts can raise equity concerns • Public opposition and protests are often reported against WTE interventions due to perceived public health and environmental concerns many of which are later validated. • Inadequate capacity of ULBs to operate and maintain WTE plants post-concession period

Type of WTE technology	Key advantages	Technical & operational challenges	Environmental Challenges	Economic challenges	Socio-institutional challenges
Decentralized biomethanation plant	• Diversion of waste from landfilling or unsustainable practices • Reducing transportation emissions and associated costs • Improved value recovery due to segregation of waste into different streams • Employment generation at local level • Located within the city - fosters community awareness and responsible waste management behaviours • Being implemented in smaller scale there is flexibility to adapt to different waste volumes and local conditions • Closing the loop on organic waste within the locality by converting it into biogas and fertilizer - more environmentally and socially sustainable transition to CE compared to centralized practices	• Lack of land availability within the city • Inconsistent waste input due to seasonal variations and lack of segregation • High moisture content in Indian MSW can affect digestion process leading to low methane yields • Regular and consistent operation and maintenance is required for the efficient functioning of biogas digestor	• Methane leakage is a potential challenge during digestion process if the plant is not well maintained • Improper effluent treatments and disposal can be a potential cause for soil and water contamination	• Small-scale plants might struggle to achieve economies of scale, making them less economically viable compared to larger centralized plants. This can lead to higher per-unit costs for biogas production. Although they can achieve break-even after a few more years with consistent operation and market demand. • Lack of forward linkages to the composts produced can hamper potential revenue generation	• Decentralized plants may face resistance from local communities due to concerns about odors, health impacts • Inadequate capacity of ULBs for decentralized SWM planning

Type of WTE technology	Key advantages	Technical & operational challenges	Environmental Challenges	Economic challenges	Socio-institutional challenges
Centralized Bio CNG plants	• Diversion of cities' whole wet waste from landfilling or unsustainable practices • Improved value recovery due to segregation of waste into different streams • Employment generation at local level • Closing the loop of organic waste at the city level facilitating CE transitions • High revenue generating potential due to large economies of scale	• Inconsistent waste input due to seasonal variations and changing consumption patterns • India's MSW typically exhibits a low volatile solid content that results in a low methane yield primarily due to lack of segregation at source • Incompatibility of MSW based Bio CNG with the vehicles due to lesser purity • Being a very sensitive technology, it requires consistent and regular operation and maintenance and adaptions as per the climatic variations • The number of CNG stations in India is limited compared to petrol pumps, which makes it challenging to sell CBG for vehicular use. Number of CNG stations is 6200 as of 2024 compared to over 70000 petrol pumps.	• Higher emissions due to transportation to centralized facilities • Large quantities of organic waste in centralized plants lead to significant odor and fly infestations, which are harder to control compared to decentralized facilities handling smaller waste volumes • Methane leakage is a potential challenge during digestion process if the plant is not well maintained • Improper effluent treatments and disposal can be a potential cause for soil and water contamination	• Higher transportation costs • High capital investments • Differential tax structure between CBG and CNG poses significant distribution challenges • Producing CBG from different feedstocks incurs varying production costs. MSW usually incurs higher pretreatment costs, which would be further increased if there is a lack of proper segregation at source • Lack of forward linkages for manure generated from slurry due to lower market demand affects the revenue generation	• Shifting waste burden to outskirts in a centralized facility raise equity concerns • Handling organic waste produces unpleasant odors and attracts flies, impacting the environment and raising health concerns among the communities nearby leading to public oppositions

5.3 Governance or institutional challenges

Governance challenges are not specific to any technology but affect all types of WTE plants.

i) **Lack of Collaborative Governance:** The handover of projects from SPVs to ULBs is often impeded by limited collaborative governance. Institutional fragmentation, with overlapping roles and responsibilities, and a lack of clear guidelines on the roles of multiple institutions, further complicates this process.

ii) **Lack of Capacity with ULBs:** ULBs often lack the capacity to make informed decisions regarding the adoption of WTE technologies suited to their specific contexts. There is a need for capacity building of ULBs both in terms of human and financial resources.

iii) **Possibilities of Technology Lock-In:** Centralized, capital-intensive projects carry a higher risk of technology lock-in, limiting flexibility and adaptability to new technologies or changes in waste composition and management needs, as we found in Jabalpur WTE.

iv) **Inclusive Privatization:** Capital-intensive technologies in waste treatment tend to attract only large private players. For smaller private agencies, government subsidies and support are necessary to ensure their participation and sustainability in the sector. Further, reliance on a single centralized plant in PPP can make ULBs in a more vulnerable position. There is a need for more private players to diversify and strengthen the sector.

v) **Economic Viability Focus:** The framing of MSWM issues is often centered solely on economic viability under SCM. This approach overlooks opportunity costs in favor of immediate cost recovery and financial sustainability, frequently neglecting broader externalities and indirect benefits. MSWM initiatives can provide significant external benefits, such as reductions in public health issues, land savings, and decreases in greenhouse gas emissions by diverting waste from landfills and dump yards, as well as reducing air and waterborne diseases. Despite these substantial advantages, such impacts are rarely considered in financial assessments. A narrow focus on revenue-generating projects risks selecting interventions that are not context-specific, potentially missing opportunities to address the broader needs of waste management. To ensure that MSWM projects contribute effectively to sustainable urban development, it is essential to incorporate these external benefits into a more comprehensive assessment framework, balancing financial considerations with the broader social, environmental, and economic impacts.

5.4 Suggestions and Recommendations

i) The techno-economic viability of any waste processing technology is dependent on the waste quantity and composition. However, most of the ULBs in India do not have regular scientific studies to assess the solid waste composition in their cities and have been following vague assumptions and projections from previous studies. It is therefore recommended to conduct regular waste audits to characterize MSW to review its suitability before adopting any waste

to energy conversion technologies. These waste audits should capture the seasonal variations and waste flows across the municipal administrative boundaries.

ii) A sustainable transition to CE should prioritize waste prevention and 3Rs before energy recovery options. For this, segregation of waste at source is crucial. Further, a decentralized approach should be prioritized where the waste gets treated and follows a circular path in the nearest possible location, which would substantially reduce transportation related emission and costs. Further, it avoids shifting the waste burden of cities to its urban peripheries, raising huge equity and justice concerns.

iii) Segregation at source is the key for the success of any waste related interventions and particularly, bio methanation plants. The success rate of biogas plants in India has been poor, is due to lack of quality feedstock. Ensuring source segregation is therefore crucial for other smart cities to replicate bio methanation plants as in Indore and Ujjain.

iv) India's experience with thermal WTE has been largely unsatisfactory. Even though many WTE plants have been proposed and implemented in the country, around half of the implemented plants have failed to operate. The reasons are attributed to lack of quality feedstock in terms of calorific value, moisture content and physical composition and lack of economic viability. In India, the percentage of wet solid waste is much higher than dry solid waste which significantly deters the economic and technical feasibility of WTE plants. The heating value of solid waste reduces significantly when improper waste segregation occurs which is detrimental from both the electricity generation and pollution viewpoint. Most of the time, the WTE plants installed would be of larger capacity than the combustible waste generated within the city. Most installed plants would have to import waste from other cities to operate the plant at full capacity. This was witnessed in the Jabalpur WTE, affecting the financial viability.

v) Jabalpur is one among the WTE plants that has sustained its operation for the longest time. While the Jabalpur WTE plant provides a potential model, replicating it widely across all smart cities is not financially sustainable and can potentially lead to a technology lock-in. Such plants should ideally function as waste sinks for a cluster of cities, only handling non-recyclable and contaminated wastes with high calorific value. This approach necessitates careful consideration of techno-economic feasibility considering two crucial aspects: availability of quality feedstock and transportation cost involved. The forward way should however be to encourage segregation of waste at source and prioritize technologies like composting and bio methanation.

vi) The emission standards in India are less stringent compared to the European standards (See Appendix 2). Many critical air quality indicators, including Total Organic Carbon (TOC), Hydrogen Chloride (HCl), Carbon Monoxide (CO), Sulphur Dioxide (SO_2), heavy metals,

dioxins, and furans, are not reported by Indian WTE plants. This is because the air emission standards for WTE plants in India do not mandate the reporting of these parameters. Further, there is a lack of strict monitoring and enforcement of existing standards, which inhibits transparency.

vii) The WTE sector is also found to adversely affect the informal waste sector. According to a World Bank study, the informal waste sector comprises 2% of the urban population in developing countries, including India. Various studies have highlighted the significant economic and environmental contributions of informal waste workers in India, despite their poor living and working conditions. However, the effective operation of WTE plants requires control over the entire waste chain, often excluding the involvement or integration of the informal sector. Since much of the recyclable waste is also combustible, these workers lose access to materials that sustain their livelihoods. Given their already deprived conditions, there is a pressing need to integrate informal waste workers into the formal waste management system to ensure their economic security and social inclusion, facilitating a just and inclusive transition to Circular economy.

viii) Bio methanation is identified as one of the feasible technologies in India along with composting, considering the higher organic and moisture content in the Indian MSW. It is mostly implemented in a decentralized manner. According to MNRE, India has installed 4.3 million household level biogas plants as of now. However, many biogas plants have also failed in India, mostly due to lack of awareness of the process among users, lack of systems in place for operation and maintenance and issues related to quality of the feedstock available. Compared to composting, it is a very sensitive technology that is greatly influenced by the input feed specifications and requires consistent operation and maintenance. Compared to composting, it is also cost intensive, but has lesser land requirements, lesser odor and threats from street dogs and rodents, making them particularly suitable for high population density areas or city centers. It also has the potential to generate higher revenue compared to composting, only if there is a sustainable and viable market available locally.

ix) The large-scale projects like Bio CNG plant in Indore can be replicable provided certain prerequisites are met that include availability of land, effective waste segregation at source, sufficient supporting infrastructure like transportation monitoring, Garbage Transfer Stations, human resources to handle these entities and community involvement. The forward linkages for the produced outputs (Bio CNG and Fertilizers) should also be ensured.

x) The Ujjain plant serves as a best practice for decentralized bio methanation models, showing financial viability if it could have operated for more years and while considering the indirect

cost savings like savings in transportation costs and tipping fees. However, in order to sustain its long-term success requires facilitating collaborative governance between multiple stakeholders involved, with clear roles and responsibilities being laid down. Further, it should be noted that financial viability should take into account the indirect costs saved due to the plant intervention like reduction in tipping fess, reduction in transportation fees etc.

xi) Promote composting technologies along with bio-methanation. Earlier in 2016, the Government of India had introduced a fixed subsidy of ₹1,500 per ton of compost sold under the Policy on Promotion of City Compost. However, the policy couldn't find its success as it did not address two critical aspects: improving compost quality and creating public demand. There were limited efforts to ensure high-quality compost, and the policy lacked testing standards, sufficient laboratories, monitoring protocols, and certification mechanisms. Furthermore, the absence of legally binding targets for fertilizer companies to market compost significantly hindered its success. The policy was completely withdrawn post 2021. The government need to re-consider providing policy support to composting by addressing the demand and supply challenges and fostering a healthy market for composting.

xii) Integrated governance structures that include representatives from SPVs, ULBs, state government departments, private sector entities, and civil society organizations. This structure should facilitate regular dialogue, coordination, and decision-making. This would facilitate long term sustenance of projects implemented by SPVs. Ensure that planning processes involve diverse stakeholders, including local communities and environmental groups. Conduct public consultations and participatory workshops to gather input and enable community ownership of projects, which is crucial in the sector of SWM.

xiii) Develop clear guidelines outlining the roles and responsibilities of SPVs and ULBs, including specific tasks for planning, execution, monitoring, and reporting. Avoid overlaps by aligning these guidelines with existing MSWM policies and frameworks.

xiv) Capacity building and knowledge sharing: Provide training and capacity-building programs for ULBs to enhance their understanding of WTE technologies and composting, project management, and regulatory compliance. Ensure that ULBs can make informed decisions tailored to local contexts. Facilitate knowledge exchange through workshops, seminars, and case study sharing.

xv) Diversify PPP models by engaging multiple private players to reduce ULB dependence on single, centralized waste treatment plants, enhancing system resilience. Introduce tiered subsidies and grants specifically targeted at smaller private players to encourage their

participation in decentralized waste management projects, such as ward-level composting, bio-methanation, and material recovery facilities (MRFs).

xvi) Integrate external benefits into economic viability assessments that accounts for indirect benefits like public health improvements, land savings etc.

xvii) Promote community engagement through awareness campaigns and educational programs. Encourage community participation in monitoring and maintaining urban projects to ensure long-term sustainability and relevance to local needs.

5.5 Checklist for decision makers while implementing any WTE technology

Table 8: Checklist for decision makers while implementing any WTE technology

Waste Quantity and Characteristics
✓ Are there scientific studies conducted by ULBs to understand waste quantity and characterization?
✓ Does the waste quantity and composition meet WTE (thermal or biochemical) requirements? (See Appendix 3)
✓ Capture seasonal waste variations and transboundary waste flow
Prioritize 3R before energy recovery
✓ Are strategies in place for waste reduction and reuse?
✓ Is there segregation of waste at source for households and commercial establishments?
✓ Are source recyclables and organics collected separately and sent to recycling and wet waste treatment facilities?
✓ Are there possibilities of decentralized interventions for community level to reduce transportation cost and emissions?
Supporting Waste Infrastructure
✓ Does systematic waste collection and transportation to the plant exist?
✓ Are there forward linkages for the electricity/Biogas/BioCNG produced?
✓ Are there forward linkages to the WTE byproducts (eg: fly ash can be used in brick industries, liquid fertilizer etc.)?
✓ Is a controlled scientific landfill available for safe disposal of unusable WTE residues (eg: bottom ash)?
Environmental aspects
✓ Do emission standards for thermal WTE follow international standards?
✓ Is there a regular real time monitoring of stack emissions in thermal WTE?
✓ Is there regular and proper monitoring of residues and emissions from the bio methanation plant?
Economic aspects
✓ Is there sufficient supply of quality waste required for running the plant?
✓ Possibilities of cost recovery for ULBs
✓ Is the energy produced accessible to local users or available for sale in the market?
✓ Is there an available market for WTE byproducts?
✓ Is the plant financially feasible in the longer run, while also accounting the indirect benefits?
Social aspects
✓ Is the informal waste sector integrated into the formal waste management system?
✓ Is there a provision of stable income and social security benefits to the sanitation workers involved in the solid waste chain?
✓ Identify the occupational health risks for workers and formulate a mitigation strategy in everyday operations and in case of serious accidents?

Governance/ institutional aspects
✓ Are the roles and responsibilities of every stakeholder clearly defined?
✓ Is there overlap of roles to be avoided?
✓ Ensure a collaborative governance by considering all relevant stakeholders in every stage from planning to implementation to operation and maintenance
✓ Is there stringent monitoring of the waste chain and operation of private entities?
✓ Is there a level playing field for more private players (including small scale private players) to invest in WTE technologies?
Risk Assessment
✓ What are the disaster (flooding/cyclone/seismic) risks involved in the location?
✓ Is there an adaptation plan (if required)?

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7. Appendices

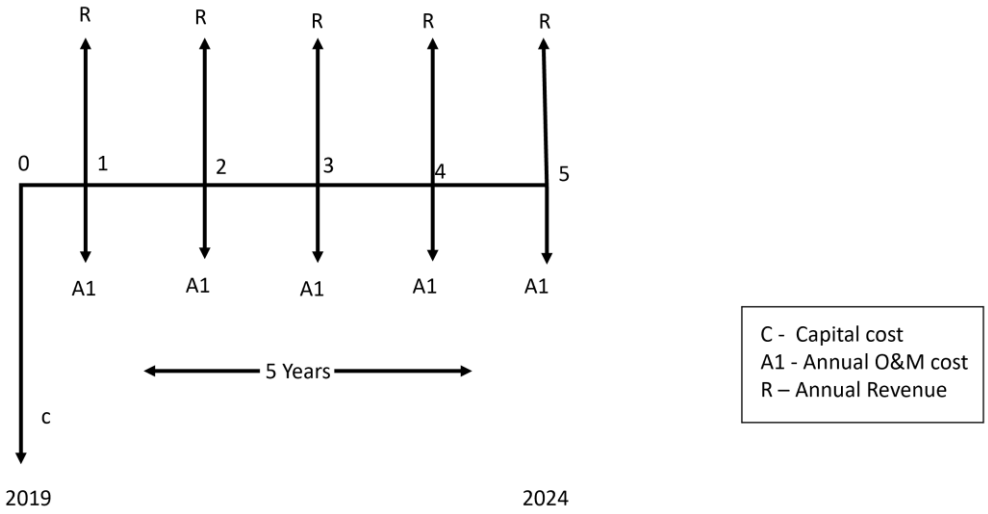
Appendix 1: Life cycle cost analysis of Ujjain Bio methanation Plant

Scenario 1 (S1): Existing scenario of plant being functional for 5 years

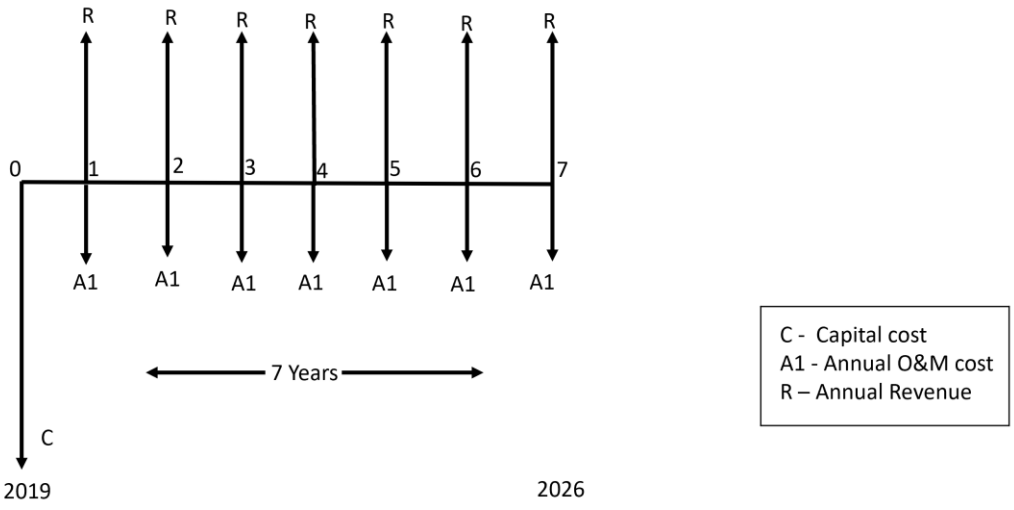
Scenario 2 (S2): If the plant could run for at least seven years

Assumptions: Annual interest rate is assumed to be 8% for both scenarios

Cash Flow Diagram (S1)



Cash Flow Diagram (S2)



Scenario1: Existing situation		Scenario 2: If the plant could run for at least seven years	
Capex (C)	11432996	Capex (C)	11432996
Opex (annual) A1	1595832	Opex (annual) A1	1595832
n (no. of years)	5	n (no. of years)	7
i (interest rate - assumed 8%)	0.08	i (interest rate - assumed 8%)	0.08
Tipping fees cost savings (annual) A2	1112000	Tipping fees cost savings (annual) A2	1112000
Revenue from sale of electricity (annual) A3	328500	Revenue from sale of electricity (annual) A3	328500
Savings in transportation fuel (annual) A4	2600000	Savings in transportation fuel (annual) A4	2600000
Total annual revenue (R=A2+A3+A4)	4040500	Total annual revenue (R=A2+A3+A4)	4040500
Annualized cost (A) (R-A1)	2444668	Annualized cost (A) (R-A1)	2444668
Single payment present worth Factor	3.992710037	Single payment present worth Factor	5.206370059
Present worth (P)	9760850.461	Present worth (P)	12727846.28
Net Present Worth value	-1672145.539	Net Present Worth value	1294850.28

Appendix 2: Emission Standards of WTE: India Vs Europe

CONTAMINENT	EU STANDARDS	SWM RULES 2016 (mg/m3)
Organic Substances (c-total)	10	20
CO	50	100
HCl	10	50
HF	1	4
SOx	50	200
NOx	200	400
SPM	10	50
Hg	0.03	0.05
Cd, Tl	0.05	0.05
Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	0.5	0.5
Dioxins and Furans	0.1 ng TEQ	0.1 ng TEQ
Minimum temperature	850°C	950°C
Retention time	More than 2 seconds	More than 2 seconds
Reference value for flue gas oxygen content	11 per cent by volume	-
Reference value for flue gas oxygen content for waste pyrolysis/gasification	3 per cent by volume	-

Appendix 3: Net calorific value of different MSW fractions

Fraction	Net calorific value (kCal/kg)
Organic	955
Plastic	8359
Paper and cardboard	3821
Metal	0
Glass	0
Cloth	4538

Source: International Solid Waste Association, 2013

Appendix 4: LULC methodology

