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Challenges of Solid Waste Management in Urban India

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Abstract

Waste generation increases as a result of rapid urbanisation and economic growth, placing tremendous pressure on the current management systems. Effective waste management has remained difficult despite the rapid economic expansion, indicating a gap in development strategies. The paper presents an in-depth study and analysis of solid waste management, highlighting the dual nature of solid waste as a challenge and an opportunity for Indian cities. It further emphasises that immediate sustainable waste management solutions are needed to solve environmental issues and achieve economic potential. Constructive approaches that involve public engagement and take geographical differences into account are essential. Through the implementation of sustainable practices such as waste disposal, reduction, reuse, and waste recovery, communities can turn waste from an issue into an asset that benefits the environment, the economy, and public health in urban areas. Although various regulations and laws have been introduced to improve waste management, such as the shift from centralised (2000) to decentralised (2016) approaches, challenges persist during the implementation process of these regulations. A shift towards responsible practices, along with investment in infrastructure, finance, technology, and awareness, are necessary to alleviate the challenges and achieve effective waste management.

Keywords: Solid waste, decentralisation, municipal finance, waste to energy plant, sustainable waste management practices

Background

As defined by Robinson (1986), solid waste refers to the byproducts of household or commercial activities that have lost their value to the original owner but may hold significance for others. The waste generated is a direct consequence of the modern way of human civilisation, presenting both challenges and opportunities. On one hand, the growing quantity of waste poses a serious issue for communities, especially in rapidly developing Indian cities striving to compete with global economies. On the other hand, it opens up possibilities for proper waste management that can not only address environmental concerns but also create economic opportunities. Despite the ambitions of Indian cities in their pursuit of rapid economic development, effective waste management has remained a significant challenge. The magnitude of waste generated has yet to be adequately addressed, highlighting a gap in the overall development strategies. The need for a more robust waste management system is evident, one that not only disposes of waste responsibly but also explores avenues for reusing materials, reducing environmental impact, and potentially generating income through proper waste management practices. In the current scenario, the dichotomy between the fast-paced economic development and the struggle to manage the escalating waste crisis poses a critical question. How can cities, aiming for global competitiveness, restore their economic aspirations with the imperative need for efficient waste management? This challenge highlights the importance of adopting sustainable waste management practices, emphasising waste disposal, reduction, reuse, and resource recovery. In doing so, communities can move beyond viewing waste as a problem and instead recognise it as a valuable resource that, if managed thoughtfully, can contribute to both environmental sustainability and economic well-being.

The responsibility of solid waste removal is mandated as an obligatory function of local governments; however, solid waste management (SWM) emerges as a major challenge for numerous urban local bodies (ULBs) in India, especially in cities characterised by high population density. India generates about 0.1kg, 0.3-0.4, and 0.5 kg per capita per day in small, medium and large cities and towns (Meena et al., 2023), and with rising per capita income, it is estimated that the waste generation per capita will increase in comparison to other south-east Asian countries like Indonesia (0.7), Thailand (1.05), Singapore (3.763), etc (Jain, 2017). The country faces unique challenges marked by various geographical and socio-economic which further complicates the implementation of uniform waste management strategies. Each region in the country may have distinct waste generation patterns and disposal preferences, necessitating distinct solutions for better solid waste management. The challenge, therefore, extends beyond the technical aspects of waste management; it requires a nuanced understanding of the regions to design and implement strategies that resonate with the local population. Public awareness and participation also become integral in encouraging sustainable waste management practices. Establishing a systematic and regular waste removal mechanism is essential to uphold a clean environment and enhance public health in urban settings (Ganesan, 2017).

Current State of Solid Waste Management in India

As cities grow and expand due to rapid urbanisation and economic development, the sheer volume of waste generated places a burden on the existing waste management infrastructure and resources. As a result, handling and disposing of this mounting waste in an efficient manner becomes a crucial task to prevent environmental degradation and associated health hazards. According to the CPCB (Central Pollution Control Board) report 2020-21, the overall quantity of solid waste generated stands at 160,038.9 tons per day (TPD) in the country. Out of which 152,749.5 TPD of waste is collected in an efficient manner. Out of the total collected waste, 79,956.3 TPD, constituting 50 per cent, undergoes some form of treatment, while 29,427.2 TPD, i.e., 18.4 per cent, is directed to landfills and 50,655.4 TPD, representing 31.7 per cent of the total waste generated remains unaccounted[3]. Meena et al., (2023) highlight that the consistent and indiscriminate disposal of Municipal Solid Waste (MSW) is intricately connected to unscientific practices, urbanisation, population growth, lifestyle ethics, and a lack of ecological awareness. For example, open dumping of MSW has detrimental effects on both the environment and human health. Solid waste management includes a spectrum of activities spanning the generation, storage, collection, transfer, transport, processing, and disposal of solid wastes (Meena et al, 2023). The mismanagement of these stages not only leads to environmental degradation but also poses a serious threat to the well-being of the residents in these densely populated urban areas.

India has traditionally adopted a centralised waste management approach, focusing on composting due to the substantial biodegradable component in its waste stream (Ganesan, 2017). In this centralised system, waste generated within a city is transported to external treatment and disposal sites. Although landfilling is a common destination for most waste, this process results in the accumulation of waste at disposal sites, depleting the Earth's assimilative capacity and

[3] CPCB (2021). Annual Report 2020-21 on Implementation of Solid Waste Management Rules, 2016. https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2020-21.pdf

causing environmental pollution. As the volume of non-degradable waste increases over time, the trenching method becomes ineffective, leading to open dumping of waste. This accumulation adversely impacts the environmental, economic, and social well-being of residents residing near landfill sites. Additionally, studies indicate that socially disadvantaged communities often inhabit areas near landfill sites, exposing them to the adverse environmental effects of waste accumulation. The environmental degradation of these neighbourhoods significantly affects the health and overall quality of life of those living in proximity to such dumping grounds.

Solid wastes originate from a variety of sources, including but not limited to residential, industrial, commercial, institutional, construction and demolition, municipal services, and process-related activities. These wastes can be further classified into biodegradable (wet waste) and non-biodegradable (dry waste) wastes (Agarwal et al., 2017).

Table 1: Types and sources of solid wastes in urban areas

Source	**Typical waste generators**	**Types of Solid Waste**
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes
Industrial	Light and heavy manufacturing, fabrication, construction sites, power and chemical plants	Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes, ashes, special wastes
Commercial	Stores, hotels, restaurants, markets, office buildings, etc.	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, office buildings, etc. hazardous wastes
Institutional	Schools, hospitals, prisons, government centers	Same as commercial
Construction and Demolition	New construction sites, road repairs, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, etc.
Municipal Services	Street cleaning, landscaping, parks, beaches, other recreational areas, water and wastewater treatment plants	Street sweepings; landscape and tree trimmings; general wastes from parks, beaches, and other recreational areas; sludge
Process	Heavy and light manufacturing refineries, chemical plants, power plants, mineral extraction and processing	Industrial process wastes, scrap materials, off-specification products, slag, tailings

Source: •Hoornweg, D. Thomas, L. (1999). What A Waste: Solid Waste Management in Asia. Working Paper Series Nr. 1. Urban Development Sector Unit. East Asia and Pacific Region. Page 5.

As per a study by Hoornweg and Thomas (1991), countries with low-income levels exhibit the smallest urban populations and the lowest rates of waste generation, typically ranging from 0.4 to 0.9 kg per capita per day. In addition, nations with a Gross National Product (GNP) per capita below US $400 tend to produce less than 0.7 kg of waste per capita daily, and as GNP rises into the middle-income range, per capita waste generation rates also increase, varying from 0.5 to 1.1 kg per day. This observed trend is intricately linked to the phenomenon of urbanisation and the rise in income levels. As urban areas in India undergo substantial growth in both population and income, there is a considerable surge in resource utilisation, consequently leading to an increase in waste production. For instance, residents of urban settings in India tend to consume nearly double the resources per person compared to their rural counterparts. This increased consumption pattern translates into a higher per capita waste output from the urban population compared to the rural population. The correlation between urbanisation, rising incomes, and increased waste generation emphasises the importance of considering socio-economic factors in waste management strategies to address the evolving dynamics of waste production. The management of solid waste is a comprehensive process that entails planning, securing finances, constructing, and operating facilities dedicated to the collection, transportation, recycling, and final disposition of the waste (Annepu, 2012).

Socio-economic challenges in solid waste management

Several critical issues and challenges plague the realm of solid waste management, including the absence of proper collection and segregation at the source, limited availability of land, indiscriminate dumping of electronic waste (e-waste), financial constraints, and a general lack of awareness. The prevalent practice in many regions, particularly in developing countries, involves the unregulated dumping of mixed waste due to financial constraints preventing the adoption of costly technologies advocated by developed nations (Agarwal et al., 2015). One significant challenge lies in the inadequate infrastructure for waste collection and separation right from the source. This often results in mixed waste streams, making it more challenging to implement efficient recycling or disposal methods. The scarcity of available land for waste disposal further compounds the problem, leading to unorganised dumping practices that can have detrimental effects on the environment. Electronic waste, characterised by the disposal of electronic devices, contributes to soil and water pollution and poses risks associated with the release of harmful chemicals and heavy metals. In addressing these challenges, it becomes essential not only to invest in infrastructure and technology but also to focus on raising awareness and encouraging a cultural shift towards responsible waste management practices.

According to the Ministry of Environment, Forests and Climate Change (MoEF&CC), solid waste management in India is regulated by the Solid Waste Management and Handling Rules (SWM) of 2000 and 2016. The 2000 rules advocate for a centralised waste management system, with municipal governments responsible for waste collection, treatment, and disposal, while the 2016 rules prioritise decentralised waste management, emphasising waste segregation and treatment at the source (Ganesan, 2017). Typically, in a centralised approaches are known to fail due to their complex linear system that extends from door-to-door collection to indiscriminate dumping in overwhelmed landfills leaving minimal room for effective management of mixed waste, on the contrary in decentralised system is operated on a smaller and more manageable scale (Iyer, 2016). It enables the processing and storage of waste, consequently enhancing its value. This value-added waste is often linked to waste traders or informal workers who serve as a knowledge pool in assessing the worth of waste. However, most Indian cities are still struggling and facing challenges to achieve decentralised solid waste management systems. For example, in case of segregating waste 100 per cent waste segregation at source is achieved only in 12 wards out of 250 of the Municipal Corporation of Delhi[4]. While Kerala has been at the forefront of this transition, the state has introduced fines of up to 10,000 rupees for individuals and commercial establishments if they fail to properly segregate and manage the waste they produce[5].

- **Segregation of waste**

A significant roadblock to the effective management of solid waste is the process of waste segregation. Before the waste is collected from sources, segregation makes the process efficient, further facilitating the recycling of the waste and reducing the cost of waste disposal. As per literature, most households (especially the households of underserved communities such as slums, etc.) and other establishments dump garbage in open spaces, drains and water bodies, and inappropriate places. It is a standard practice in affluent countries like the USA, Germany, Japan, etc., while most developing countries, including India, collect municipal solid waste in mixed form. This aspect can be attributed to a number of factors, such as low public knowledge and slower progress in methods for sorting garbage at the source. Acknowledging the significance of source separation is essential to improving recycling operations in an effective and efficient manner. Due to the absence of waste segregation, recycling wastes has been associated with the informal sector through old-fashioned technology; however, this also leads to the production and demand of cheap and affordable products in the market (Balasubramanian, 2008). Paper and plastics are some common examples of these products. Several developed nations, such as France, Austria, etc., have formulated laws and regulations to enforce mass recycling of solid waste to cope with waste generation on a daily basis.

Implementation of waste segregation practices in Asian municipalities

The Yokohama G30 Plan, otherwise known as the Yokohama Municipal Solid Waste Management Master Plan, is a classic example of enhancing solid waste management services. A thirty-percentage reduction of waste volume by 2010 in comparison to the levels recorded in 2001 was the objective behind this initiative. The plan entailed infrastructure improvements, stringent monitoring and enforcement and mandatory source separation. The number of categories for waste segregation increased from five to ten that covered more materials. In order to ensure effective segregation at source, people were advised to bring their pre-sorted garbage to designated collection points. Moreover, extensive knowledge has been spread among citizens about how they can separate their waste properly – this has added a contributing factor towards being successful in this area. Some public meetings were conducted within the first two years; this encouraged residents to develop environmental consciousness and sustainable waste management practices soon afterward. Batam municipality in Indonesia also practices compulsory classification of wastes into recyclable, hazardous and domestic ones.

The municipality of Trichy initiated a trial of Quick Response (QR) codes which were distributed among residents and businesses who live in and around selected wards. Waste collectors utilise the QR codes during collection and scan the codes at each designated collection point. The process enables real-time data entry online, ensuring that no collection spots are left. A similar initiative was implemented in Bengaluru, emphasising proper waste segregation. Waste collectors

[4] 100% segregation of waste takes place in just 12 wards. (2024, March 3). The Times of India. https://timesofindia.indiatimes.com/city/delhi/100-waste-segregation-in-only-12-municipal-wards-delhi-economic-survey-report/articleshow/108172210.cms

[5] Bureau, T. H. (2023, October 11). Kerala Cabinet approves Ordinance for stricter waste management laws. The Hindu. https://www.thehindu.com/news/national/kerala/cabinet-approves-ordinance-for-stricter-waste-management-laws/article67408566.ece#:~:text=The%20Kerala%20Panchayat%20Raj%20(Second

in Bangalore are required to upload photos of non-segregated waste along with the relevant QR code, thereby enhancing the monitoring of waste segregation efforts (EPA, 2020).

These kinds of strategies contribute to a more sustainable waste management system by ensuring a higher quality feed material with fewer pollutants in addition to enhancing the performance of waste treatment units. Meena et al., (2023) identified that the most significant waste management principle is the segregation of waste at source. It demands waste to be separated at the source, which includes homes, offices, schools, and marketplaces. This first stage guarantees that different waste categories are separated properly right from the start of the waste management cycle.

- **Collection and Transportation of waste**

Waste collection, storage, and transportation are essential parts of any solid waste management system, and the implementation of these tasks can be quite challenging. As per Municipal Solid Waste Management Rules 2016, there are two kinds of waste collection methods, namely primary and secondary collection. The former involves the waste collected from the source it is generated, while the latter refers to the waste collected from sources such as community bins, storage, etc., to the processing or disposal location. In India, waste is collected formally and informally due to various factors, such as inadequate finance, lack of efficient technology, shortage of trained workers, etc. Balasubramanian (2018), in his study, highlighted that the schemes of solid waste management collection benefit only some sections of the urban population because the available resources and capacity of planning are not able to cope with increasing waste generation.

As discussed earlier, municipal corporations are in charge of collecting waste in the country, and they usually provide bins for separating waste into categories such as biodegradable and inert. Unfortunately, the practice of disposing of mixed biodegradable and inert waste in the open continues, frequently resulting in open burning as a prevalent form of disposal. In India, the lack of a well-established primary waste collection system is evident, with underdeveloped waste storage infrastructure at its source and a limited door-to-door waste collection, which, when implemented through private sweepers or departmental efforts, often lacks synchronisation with waste storage depots and transportation facilities (Balasubramanian, 2018). Local authorities should ensure daily waste collection services for all residences, businesses, and establishments; however, the current practice is limited, with only major roads and markets receiving daily sweeping, while certain streets are addressed on alternate days or bi-weekly, and others are rarely or never cleaned. Balasubramanian (2018) emphasises that the absence of a systematic plan results in irregular street sweeping, aggravated by the lack of a standardised benchmark or guideline set by municipal authorities. In some areas, sweepers are assigned tasks based on road length, typically ranging from 250 meters to 1 km, while in other locations, measurements are made in square meters. This lack of uniformity highlights the need for comprehensive planning and consistent standards to ensure regular and efficient street-sweeping practices across the country. Overcoming these obstacles and developing India's waste collection and transportation infrastructure could lead to increased employment, better public health, and increased tourism.

- **Disposal and treatment methods**

Disposal and treatment of solid waste management is a critical issue in the development and growth of human settlements worldwide. Merely discarding solid waste out of sight does not resolve the problem; instead, it often exacerbates the problem, leading to a multitude of adverse consequences. Over time, this unchecked disposal can spiral out of control, posing serious challenges for everyone involved. In India, a staggering majority, exceeding 90 per cent, of municipal solid waste in urban areas is disposed of directly onto land in unsatisfactory conditions (Kumar et al., 2017).

Waste dumps have significant adverse effects on both the environment and public health. As per the CPCB report 2020-21, 3184 dumpsites have been identified. Out of these, 234 are reclaimed, and 8 of them have been converted to landfills. Open dumps emit methane gas as biodegradable waste decomposes in anaerobic conditions, contributing to fires, explosions, and global warming. Additionally, odours and leachates from dumps can contaminate nearby water sources, posing health risks, especially during India's hot summers when temperatures can exceed 45°C (Kumar et al., 2017). Uncontrolled burning of waste at dumpsites releases fine particles that contribute to respiratory diseases and smog. In Mumbai alone, the open burning of municipal solid waste and tyres emits a significant amount of pollutants into the atmosphere each year (Annepu, 2012). Therefore, addressing poor waste management practices is crucial not only for environmental preservation but also for safeguarding public health.

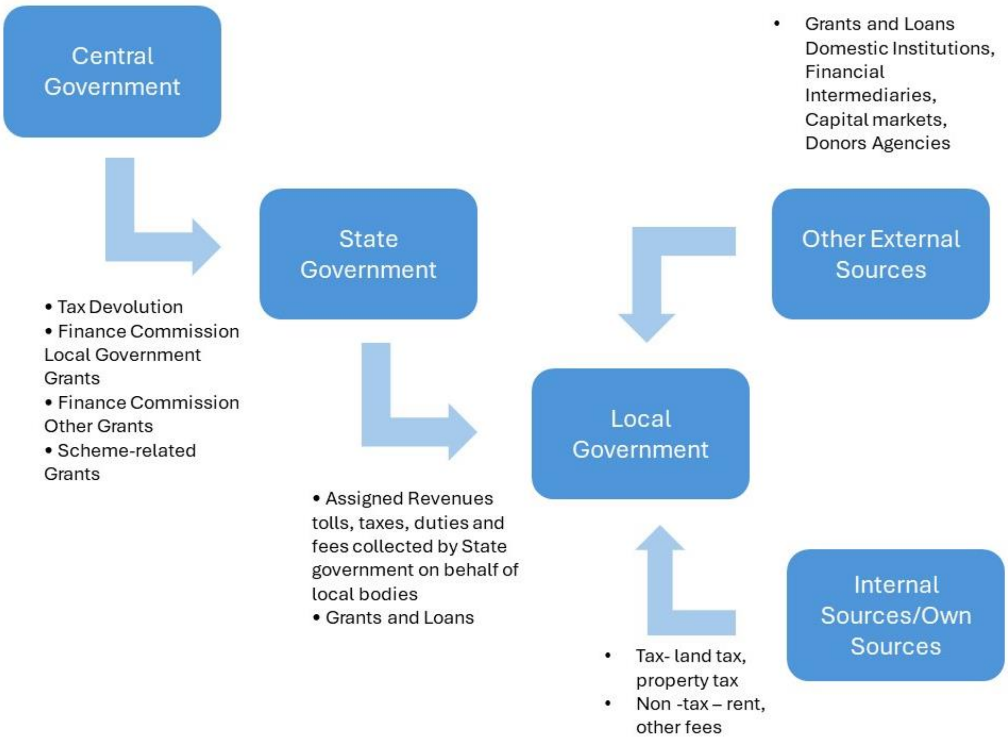
According to a study by Sharholy et al. (2008), two prominent innovative methods of waste disposal are gaining traction in the country: composting, which includes aerobic composting and vermicomposting, and waste-to-energy (WTE) technologies, such as incineration, pelletisation, and biomethanation. The study also highlighted that while waste-to-energy projects for municipal solid waste disposal have been successful in developed nations, they are still relatively new to India. However, their widespread implementation in India is hindered by ongoing evaluations of financial viability and sustainability. In many metropolitan cities, such as those emphasised in Sharholy et al.'s study (2008), the prevailing practice of open, unregulated, and poorly managed dumping has resulted in severe environmental degradation. This substandard dumping, especially prevalent in coastal towns, has had dire consequences, including the rapid leaching of heavy metals into coastal waters, which increases environmental concerns. For instance, the dumping of waste without proper containment measures can lead to pollutants seeping into groundwater sources, contaminating both the water supply and the surrounding ecosystem. For example, cities like Delhi, in particular, face acute challenges in waste management due to the scarcity of available land for disposal purposes. With limited space to accommodate the growing amounts of waste generated by an expanding urban population, existing landfill sites are under immense pressure. This not only presents logistical challenges in terms of waste disposal but also raises serious environmental concerns.

- **Inadequate municipal finance**

Adequate municipal finance is required to enable local governments to fulfil their mandates and deliver a range of essential services (Mehta et al., 2020). Challenges related to municipal finance are widespread in developing and under-developed countries, mainly due to their restricted capacity to handle various issues. According to the World Bank (2020), some of these issues include – struggling to make enough money from the services they provide and covering their costs; having complex and confusing organisational structures with overlapping responsibilities;

not having all the necessary information to plan their spending on infrastructure and development effectively; and failing to develop successful partnerships with private businesses to address urban challenges. Various factors contribute to municipalities and municipal agencies facing challenges in attracting private capital on market terms due to inadequate creditworthiness profiles. It is important to have operating income exceed operating expenditures, including interest on existing debt, to increase the creditworthiness of municipal agencies. And then this surplus can then be used to make service payments on any new loans. According to a report by the Reserve Bank of India (2022), municipal revenues and expenditures in India have remained stagnant, hovering around 1 per cent of the GDP for over a decade. This is in stark contrast to countries like Brazil and South Africa, where municipal revenues and expenditures make up a much larger portion of the GDP, accounting for 7.4 per cent and 6 per cent, respectively (Mehta et al., 2023).

Flow of Municipal finances



Source: Reserve Bank of India, 2022

Globally, municipal financing for solid waste management is a critical sector. The majority of the investment expenses for waste systems are borne by the private sector and national government subsidies, with local governments often only covering roughly half of these costs. It is uncommon for the central government to directly regulate solid waste services; instead, most services are governed by local municipal bodies. These services often involve a mix of public and private sector participation, with approximately one-third operating under public-private partnerships. Services such as collecting, transporting, processing and disposing of solid wastes significantly depend on available finance. Due to lack of financial constraints, the local bodies or municipalities implement these services in a poor manner. As a result, they fail to establish sufficient number of composting or other waste disposal facilities with varying capacities. This shortfall leads to an increase in the organic load on landfill sites and also adds up to higher greenhouse gas emissions from these landfills. In addition, the available funds are not utilised efficiently. According to an advisory report by the Central Public Health and Environmental Engineering Organization (2013), a huge portion of the available budget is allocated for waste collection and transportation rather than disposal methods. Before allotting funds efficiently, it is important to first prioritise the analysis of the collected waste and then identify the predominant types of waste in specific areas. The report also highlights that in the majority of urban centres, expenditures on solid waste management fall between 5 to 40 per cent of the total budget, corresponding to approximately Rs 50-250 per capita. Besides, it is noted that a considerable portion of this expenditure is directed towards salaries, leaving limited funds available for operation and maintenance (O&M) and development projects within the sector.

Municipal bodies are responsible for administering various civic services, and the scope of their activities typically expands with the size of the city they serve. For example, in smaller towns where solid waste management is a primary focus, this sector alone receives as much as 70% of their budget allocation whereas metropolitan cities that are required to offer a more extensive range of services only commit about 10% of their budget to solid waste management (CPHEEO, 2013). As per the current SWM framework, local bodies in India allocate approximately Rs. 500–1000 per tonne, with the majority (70%) directed towards collection and a meagre portion (20%) allocated for transportation of waste (Kumar et al., 2017). Municipal financing and institutional arrangements dynamics create specific challenges for covering investment costs and promoting effective public-private partnerships. In essence, improving municipal finance programs should be prioritized through investments because it forms an important foundation for enhancing the delivery of solid waste management services. Nonetheless, when financial matters such as revenue generation or cost recovery mechanisms or investment planning relating to municipalities are addressed efficiently resources can be directed better towards projects on solid waste management. This will not only ensure sustainable funding for waste management projects but also ease implementation of efficient and inventive solutions. Ultimately, by integrating solid waste management into municipal finance strategies, cities can achieve better outcomes in waste management service delivery, contributing to environmental sustainability and public health.

- **Technology and capacity building of municipal workers**

Selecting an appropriate disposal technology is an essential aspect of efficient solid waste management. According to various literature, it is widely observed that the equipment and machinery utilised are either remodelled for general use or borrowed from other industries. Nevertheless, this approach can lead to excessive utilisation of already existing resources, thus reducing their effectiveness. The management of municipal solid waste is quite different from other sectors because it involves a complex process of technology transfer. Therefore, there is a need for adoption of indigenous technologies to comprehend this phenomenon such as local waste analysis machinery (CPHEEO, 2013). Recycling, reusing and composting, among others, when practised well, can be helpful in improving solid waste management. For example, in Vietnam, Danang city has an objective of recycling 12% of their municipal solid waste. They have done pilot projects and worked with other government bodies/private companies to implement the recycling process. The community has created committees to enable public participation during the planning stages. Moreover, differences in countries' waste profiles, as well as local conditions, may pose huge challenges in implementing foreign innovations concerning these areas.

Additionally, having a well-trained workforce is crucial for implementing adopted technologies accurately and efficiently. Unfortunately, in many cases, the staff employed by local bodies and municipalities for waste disposal lack adequate training, motivation, and efficiency. This deficiency highlights the importance of investing in training programs to equip personnel with the necessary skills and knowledge to execute waste management procedures effectively. By ensuring that staff are properly trained and motivated, local authorities can enhance the overall efficiency and effectiveness of waste management practices.

Interventions to improve solid waste management practices

Solid waste management (SWM) requires a significant amount of capital investment; however, due to the current financial state of the urban local bodies/municipalities, they are unable to commit to any large-scale capital expenditures for SWM projects. Therefore, the solid waste sector demands exploring structured strategies and alternative funding sources along with setting up a definite target to achieve. This section has been divided into two parts: strategies and funding sources. Below is a table with some financing solutions followed by their explanation:

Funding sources for solid waste management	
Tax financing	In many Indian cities, revenue for solid waste management is limited by inadequate property tax assessment. The current model lacks incentives for efficiency since financing is intricately tied to property taxes. Developing a remunerative model of dedicated tariff could be a way to address this problem. Tariff structures can contribute to increasing revenue for solid waste management, although the process requires careful monitoring.
Waste-to-energy plants	For Waste-to-Energy (WtE) plants, a viable power tariff has the potential to offer adequate financial support for waste management, which includes collection, transportation, and processing. They can generate a steady source of income and they can be utilised for restoring existing landfill sites by placing them in appropriate locations. Consequently, it reduces the amount of waste that ends up in landfills.
Composting	Composting can become a financially operational venture by setting a mandatory off-take price of Rs 5000[6] for compost by the fertiliser companies. This will attract private investment and ensure that compost producers have a guaranteed market with a stable income.

- **Role of tax financing: A Remunerative model**

[6] The findings of the business model for composting highlight that for higher profit margins, the off-take price of compost should be increased.

One serious issue is the poor assessment and collection of property tax in many Indian cities, resulting in a limited revenue base for solid waste management. Traditionally, funding for solid waste management systems in municipalities or local bodies has relied on the general fund, often supported by a percentage of property tax designated as the conservancy tax. As per a report by CPHEEO (2013), this tax financing model lacks a direct link between income and expenditure for waste services, thus providing little incentive for local bodies to implement efficiencies in their operations. In short, the current system for solid waste management is tied to property tax percentages, limiting the potential for further increases due to legal constraints. Moreover, revisions to property tax rates occur infrequently.

In response to these challenges, it is proposed to introduce an additional dedicated tariff specifically for solid waste services. This new tariff structure could be based on various factors, such as the frequency of waste collection, the volume or weight of waste generated, or a combination of both. Additionally, it may be designed on a per-family basis to ensure fairness and accuracy in billing. Different tariff structures would need to be delineated for distinct waste collection systems, such as community bin systems and house-to-house collection systems. For example, Bengaluru is planning to introduce a SWM user fee to generate revenue and improve the overall system of solid waste management[7]. Each structure should outline the methodology for estimating and recovering charges, ensuring transparency and accountability in the entire process. Provisions should also be made for the transportation and disposal of commercial, industrial, construction and demolition wastes because these wastes are mostly hazardous and require appropriate treatment. This will further include the formation of a clear set of rules and guidelines to charge/recover the costs associated with these services. In order to accommodate the changing dynamics of various economic and environmental factors, the tariff framework should have mechanisms for periodic revision of the rates, and this further ensures that the tariff remains responsive to evolving needs and circumstances.

In certain cases, outsourcing specific tasks related to solid waste management may be considered, particularly for identified occupations. However, any outsourcing contracts should be carefully formulated to include robust monitoring and penalty mechanisms, safeguarding against potential inefficiencies or non-compliance issues. By implementing these measures, municipalities can establish a more flexible and sustainable framework for funding solid waste management services, ensuring the efficient and equitable provision of these essential public goods.

- **Efficient waste treatment methods**

A significant section of solid waste management is dependent on efficient waste treatment methods because it contributes to reducing the amount of waste that is dumped on open sites and facilitates a circular economy by focusing on reusing, recycling, and recovering resources from waste materials. Waste-to-energy and composting have tremendous opportunities; this section illustrates their potential to improve waste management through a tariff-based business model.

Waste-to-energy recovery - While waste-to-energy is a common method of waste treatment practised in the country, its implementation is insufficient compared to the volume of waste generated nationwide. In cases where material recovery from waste is not feasible, energy recovery from waste becomes a preferred option. This involves generating heat, electricity, or fuel from the waste through a variety of processes that include combustion, gasification,

[7] Bureau, T. H. (2023, October 9). Traffic, garbage and property tax key priorities of Brand Bengaluru, says D.K. Shivakumar. The Hindu. https://www.thehindu.com/news/national/karnataka/traffic-garbage-and-property-tax-key-priorities-of-brand-bengaluru-says-dk-shivakumar/article67400185.ece

pyrolization, anaerobic digestion and landfill gas recovery[8]. India has 12 waste-to-energy (WTE) plants operating as of November 2022; another 8 units are located throughout 10 states but are not in operation[9]. Some of the operational WTE plants include Pune's plasma-gasification-based hazardous WTE plant, which has a capacity of 700 TPD, and Refuse Derived Fuel (RDF) based plants located in Delhi, Hyderabad, Bengaluru, etc. Usually, municipal solid waste is burned in the waste to energy plants to create steam, which powers electric generators to provide energy. Even though the nation has the ability to generate 5,690 MW of electricity from MSW and industrial trash, as of May 2023, only 556 MW of that capacity had been constructed.[10] This indicates that there is considerable unrealised potential within the waste-to-energy sector in India. If the sector is explored and expanded to a large scale, it has numerous compelling advantages, such as reducing the country's dependence on fossil fuels, easing pressure on available landfills, etc. Furthermore, these facilities contribute to job creation that supports local economies and livelihoods. In addition, this sector can also contribute to achieving SDGs and promote circular economy.

Globally, landfills equipped with systems to capture and utilise methane gas are favoured over those that do not capture the gas. Recovering energy from the combustion of solid waste is an integral step in handling non-hazardous wastes. Within the waste management hierarchy, this method ranks in between i.e., better than treating or disposing waste but below reducing and recycling/reusing the waste. When the waste is burned in a controlled way, it not only reduces the amount of waste going to landfills but also creates energy we can use. The process further helps to cut down on pollution from using fossil fuels and reduces the methane gas produced by landfills, which is good for the environment. Citing the example of Delhi, which faces a significant solid waste management challenge, with only 72.3% of waste processed in existing facilities and aims to expand the waste to energy plants to address the issue. According to the Delhi economic survey report for 2023-24, Municipal Corporation of Delhi (MCD) generates about 11,000 tonnes of waste per day, while New Delhi Municipal Council and the cantonment region produces 311 and 65 tonnes respectively[11]. The city has four waste-to-energy plants, namely Okhla, Ghazipur, Narela, and Tehkhand, which have a capacity of 6550 TPD to process in total. Through the city, the existing capacity of waste processing facilities is approximately 8224.5 TPD of waste, which amounts to 72.3% of the total waste generated[12]. This means that the remaining municipal solid waste (about 35%) is either sent to landfills or disposed of in an unsatisfactory manner. Therefore, several waste-to-energy facilities are in the process of development to improve waste management. As per the report, by 2026, a new plant with a capacity of 3,000 tonnes in Narela-Bawana is expected to start operations, followed by another plant in Ghazipur with a capacity of 2,000 tonnes by 2027. Similarly, Chennai Corporation has shifted to an integrated waste management facility featuring a waste-to-energy plant that will be

[8] United States Environmental Protection Agency. (2019, February 15). Energy Recovery from the Combustion of Municipal Solid Waste (MSW) | US EPA. US EPA. https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw

[9] How India can rejuvenate its Waste-to-Energy sector - ET EnergyWorld. ETEnergyworld.com. Retrieved March 9, 2024, from https://energy.economictimes.indiatimes.com/news/renewable/opinion-how-india-can-rejuvenate-its-waste-to-energy-sector/103030931#:~:text=The%20process%20involves%20converting%20garbage

[10] How India can rejuvenate its Waste-to-Energy sector - ET EnergyWorld. ETEnergyworld.com. Retrieved March 9, 2024, from https://energy.economictimes.indiatimes.com/news/renewable/opinion-how-india-can-rejuvenate-its-waste-to-energy-sector/103030931#:~:text=The%20process%20involves%20converting%20garbage

[11] 100% segregation of waste takes place in just 12 wards. (2024, March 3). The Times of India. https://timesofindia.indiatimes.com/city/delhi/100-waste-segregation-in-only-12-municipal-wards-delhi-economic-survey-report/articleshow/108172210.cms

[12] 100% segregation of waste takes place in just 12 wards. (2024, March 3). The Times of India. https://timesofindia.indiatimes.com/city/delhi/100-waste-segregation-in-only-12-municipal-wards-delhi-economic-survey-report/articleshow/108172210.cms

implemented on a separate land instead of the initial proposal of utilising reclaimed land from a dump yard[13].

Financial viability analysis of a Waste-to-Energy (WTE) plant: A business case study

Energy Mix = 100% = 2302473330 kWh (2302083330 + 390000)					
S.No	**Particulars**	**Details**	**Non-WTE Electricity**	**Column 1 - WTE Electricity** **Scenario 1 (Power tariff range at Rs 8)**	**Column 2 - WTE Electricity** **Scenario 2 (Power tariff range at Rs 20)**
A	**Share of Consumption**		99.98% (2302083330 kWh) for normal	0.017% (390000 kWh) for WTE	0.017% (390000 kWh) for WTE
B	**Cost of Consumption**		Rs 6 kWh (assumed)	Rs 8 kWh (assumed)	Rs 20 kWh (assumed)
C	**Cost in the mix**	**A*B**	Rs 5.99 kWh	Rs 0.136 kWh	Rs 0.34 kWh
D	**Cost to consumers per unit**	**C+ (Cost in the mix arrived in Respective Columns or Scenarios)**		Rs 6.126	Rs 6.33

Explanation of the case:

The rationale for the business venture is to shed some light on the potential benefits of waste-to-energy plants when they are utilised effectively. According to available literature, the Ghazipur WTE plant has the capacity to generate 13 MW per day, equivalent to 13000 kWh. Therefore, it can produce 390000 kWh in a month (13000 * 30), while Delhi generates 27625000000 KWh of electricity in a year, i.e., 2302083330 (27625000000/12) kWh in a month.

We have calculated the energy mix by adding the amount of the electricity generated by a waste-to-energy plant and the total electricity produced by the city, which yields a total of 2302473330 kWh. Calculating the share of consumption for non-WTE electricity and WTE electricity is 99.98% and 0.017%, respectively. To develop our model, we have assumed varying power tariff rates, with non-WTE electricity priced at Rs 6 per kWh and WTE electricity priced at Rs 8 and Rs 20 per kWh. By multiplying the respective share of consumption by the corresponding cost of consumption, we have calculated the cost in the mix for each scenario. For the two WTE plant scenarios, the cost to consumers per unit is Rs 6.126 and Rs 6.33, respectively, depending on the chosen power tariff range of Rs 8 or Rs 20 per kWh.

[13] Chennai Corporation to start operations of waste-to-energy plant in Kodungaiyur in two years. (2024, March 9). The Hindu. https://www.thehindu.com/news/cities/chennai/chennai-corporation-to-start-operations-of-waste-to-energy-plant-in-kodungaiyur-in-two-years/article67932927.ece/amp/

Hence, when the power tariff for WTE plants is increased from Rs 8 to Rs 20 kWh, there is a minimal increase in the cost of electricity to customers per unit. Even a significant rise in their tariff will only have a limited effect on the overall cost to consumers because WTE plants only contribute a small portion of the total energy output. This suggests that there is enormous untapped potential in the WTE plants sector.

Composting - Organic wastes can be processed either aerobically or anaerobically to produce useful products. Compost is created when wastes are treated aerobically, whereas anaerobic treatment produces biogas and wastewater with the potential to be used as biofertilisers. Air decomposition is a sustainable waste management method that is exemplified by composting. Microorganisms decompose organic complexes into organic and inorganic byproducts throughout this process. These derivatives are distinct from those found in coal, peat, or natural soils because of their special humus-like qualities. The process of composting involves transforming naturally occurring waste species into beneficial and safe products as soil amendments and biofertilisers (Ayilara et al., 2020). Contributing to environmental protection is one of the key advantages of composting. Compost aids in maintaining the quality of groundwater, in contrast to landfills, which present a risk of contamination to groundwater sources. Additionally, compost application enhances agricultural productivity and soil organic matter content. This is attributed to the nutrients present in compost materials and the presence of beneficial microorganisms that promote plant growth. Beyond just being a fertiliser, compost offers a lot of other uses, such as aiding in bioremediation efforts, avoiding pollution, weeds and plant diseases, lessening erosion, and assisting with landscaping and wetland restoration. Compost also promotes soil biodiversity, which is related to agricultural yield on the soil. Additionally, it lowers environmental dangers. Overall, composting enhances soil health, agricultural output, and ecological resilience while being a greener solution.

Mysuru city has an advanced organic waste management system that effectively converts the city's organic waste into compost for agricultural use and the municipality actively promotes decentralised waste management practices, encouraging households to engage in composting to transform kitchen waste into a valuable resource[14]. Under the supervision of the Mysuru City Corporation, the city operates a centralised composting facility, which acts as a hub for the treatment of mixed garbage gathered from different parts of the city and excess material from zero waste management plants. In a similar way, Mangaluru has adopted proactive measures in response to the growing problem of solid waste management. A bio-composter has been installed by Give Green Solutions, which efficiently breaks down wet waste by using bacteria. Currently, the city's 8,000 households—84 of which are individual households and apartments—are actively engaged in turning at least six tonnes of wet waste every day into compost[15]. Mandaue City of Philippines has the most structured waste separation system that separates bio-wastes for composting is seen as a regular practice. It is important to point out that a substantial amount of organic waste is found in solid waste; thus, appropriate segregation is fundamental for achieving recycling goals and ensuring the quality of recyclable products. In addition, unlike other cities where there are strict requirements for waste separation procedures, Mandaue City disposes its waste at a sanitary landfill operated by a private company. The initiative emphasises the crucial role of the community in implementing cutting-edge techniques to properly manage waste and lessen its negative effects on the environment.

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[14] India's cleanest cities: Mysuru's sophisticated decentralised wet waste-to-compost system. (n.d.). Www.downtoearth.org.in. Retrieved March 9, 2024, from https://www.downtoearth.org.in/video/waste/india-s-cleanest-cities-mysuru-s-sophisticated-decentralised-wet-waste-to-compost-system-81307

[15] Kamila, R. (2020, November 2). 8,000 houses converting wet waste into compost in Mangaluru. The Hindu. https://www.thehindu.com/news/cities/Mangalore/8000-houses-converting-wet-waste-into-compost-in-city/article33006785.ece

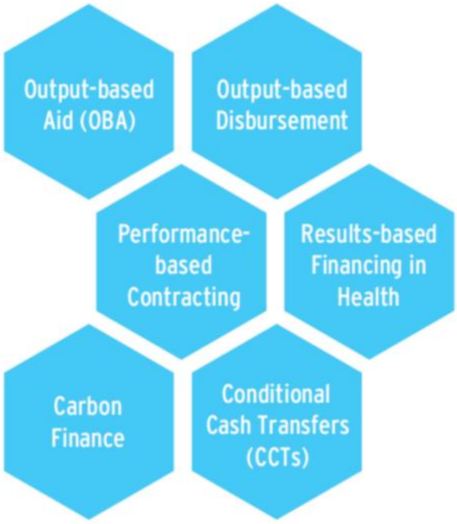
India produces a significant amount of organic waste, including food scraps and yard waste, indicating remarkable opportunity in this sector. Composting these materials reduces the volume of waste that is sent to landfills, helping to alleviate the strain on already overburdened waste management systems. Assuming the cost of investment for a composting facility is Rs 10 crores, which has a capacity of 100 TPD of waste and is functional 5 days a week[16]. So, in a year, the capacity of the plant is 24000 tonnes. Land is provided by the government. The compost plant's finances have been divided into owner's equity (24 per cent of the total project cost, i.e. Rs 24000000) and debt (74 per cent, i.e. Rs 74000000) at an interest rate of 14 per cent (Gebrezgabher et al., n.d.). Therefore, the composting plant pays an interest of 10360000 per year. The sales of compost per year are Rs 76800000 crores, where we assume Rs 3200 per tonne is the offtake price of compost (excluding the transport cost). While operations and maintenance (O&M) cost is Rs 48000000 (Rs 24000*2000) per year, when O&M cost is assumed at Rs 2000 per tonne. The profit, which is calculated by deducting the operating and maintenance expenses and the interest expenses from the sales revenue (Sale Revenue – (O&M + Interest Expenses), amounts to Rs 1.844 crores per year. This profit translates to a Return on Investment (ROI) of 18.44 per cent, which is the percentage of benefits derived from the level of investment or cost incurred for it. Therefore, to get an ROI of 35 per cent, there needs to be a profit of Rs 3.5 crores. This means that to increase profit margins, the offtake price of compost should be increased.

- **Result-based financing to enhance solid waste management**

Considering solid waste management as a sector that faces challenges related to finance and at the same time has high demands for good service, Result-based financing (RBF) is a valuable payment mechanism through which rewards or incentives are provided to the service providers after fulfilling pre-agreed targets (The World Bank and GPOBA, 2014). This method ensures that public funds are utilised in an efficient and transparent manner, while incentivizing the waste collectors to maintain high standards. RBF can also serve as a tool to encourage community engagement and participation in waste management initiatives. For example, community groups can be incentivized through rewards to organize themselves and adopt constructive behaviours such as waste segregation, recycling, and enhancing cleanliness in their neighbourhoods. This further promotes a sense of ownership and responsibility among the communities towards managing their waste effectively. RBF also has the potential to outreach underprivileged areas and improve access to basic amenities by facilitating the transfer of donor funds to various countries. RBF has a variety of instruments which has been designed to improve service delivery or infrastructure by providing funding if pre-determined goals are achieved, some RBF examples include output-based aid, conditional cash transfers, advance market commitments, and carbon finance (The World Bank & GPOBA, 2014).

Potential instruments for result-based financing

[16] The figures for the calculation have been assumed based on our stakeholder interaction with Climate Circle and existing literature.



Source: The World Bank and GPOBA, 2014

Output-based aid (OBA) is a form of result-based financing that provides subsidies based on performance to deliver essential services to economically disadvantaged populations such as slums/squatter settlements, etc. These services include water, sanitation, electricity, transportation, telecommunications, education, and healthcare. OBA subsidies serve to complement or replace user fees in cases where public policy deems it necessary to ensure access to these services for the underprivileged. The primary goal is to incentivize service providers to extend their services to impoverished households, where market incentives alone may not be sufficient. By identifying recipients and setting clear performance metrics, OBA aims to reduce economic distortions associated with traditional subsidy models. Subsidies can take various forms, such as one-time grants, transitional support, or ongoing financial assistance, depending on the service and context.

Case studies on incentivising performance of solid waste services through result-based financing

RBF has been adopted in several middle to low-income countries such as Nepal, China, Malaysia, Indonesia, Tanzania, etc., to improve services related to solid waste management (The World Bank and GPOBA, 2014).

In Nepal, RBF subsidies are utilised by various projects to enhance the financial viability of solid waste services by increasing collection of user fees while boosting the waste collection services at the same time. This is done by providing an output-based subsidy to the participating municipalities that will help in addressing the gap between the total costs involved in providing SWM services (capital costs, operation and maintenance costs, etc.) and the revenue generated by the municipalities through the services. The subsidy payment is based on service quality improvements and the design of the subsidy is intended to decrease over time as services improve and fee revenue increases. The design also assumes that when residents see visible improvements in their waste management services, they become more willing to pay for those services. Every year, after checking the status of the improvements, the subsidy amount is calculated using a set number, which can change depending on how much money the service provider needs to cover its costs and how much it can get from user fees. Over four years, this number gradually changes so that by the end, the city can keep providing the services without needing any extra subsidy money—it can rely on the fees people pay for the services instead.

China, Malaysia and Indonesia practice a model that incentivizes households in source separation and collection of waste through changes in their behaviour. In Ningbo municipality of China and Penang of Malaysia, the communities receive cash awards if they segregate the wastes into the given categories like food wastes, recycles, hazardous wastes, etc. The separated waste is further assessed based on pre-determined quality and quantity, the communities are provided with scores and based on the acquired scores they are incentivized with cash awards with a minimum and maximum amount. While in Indonesia, cities are encouraged to promote recycling in households by setting up local waste banks using RBF. The waste banks operate as per the pre-determined targets and the cities receive incentive after they get a minimum number of households to participate and ensure the waste banks run smoothly. The money earned by the cities are used for local community projects. The level of awards also varies depending on the how well the cities perform in getting more people to recycle more. The progress of the program is monitored at three stages such as: planning and implementation of the waste banks, their development and growth, and lastly their sustainability over a long period.

In Tanzania, communities living in low-income areas receive financial support through RBF over a period to improve both primary and secondary waste collection services. Hand cart collectors who collect door-to-door wastes are paid based on how many households they serve regularly, how much they improve in covering their costs, and whether they transport the waste to approved locations, that helps prevent illegal dumping. Simultaneously, cities also receive payments for secondary waste collection based on how much waste they remove each day, if they dispose of it properly, and the amount of waste that gets recycled or composted. Overall, this approach aims to improve waste management services in these communities while ensuring proper disposal and reducing environmental harm.

Carbon finance - Another instrument of RBF is carbon finance, which can help in efficient solid waste management and contribute to reducing greenhouse gas (GHG). The government of India is working towards establishing the Indian Carbon Market (ICM) as part of its efforts to decarbonise the economy, and this initiative aims to price greenhouse gas (GHG) emissions by facilitating the trading of Carbon Credit Certificates[17]. The Bureau of Energy Efficiency under the Ministry of Power, in collaboration with the Ministry of Environment, Forest & Climate Change, is spearheading the development of a Carbon Credit Trading Scheme to facilitate this process. After the Kyoto Protocol was adopted, the Clean Development Mechanism (CDM) was created to enable developed countries to support climate change mitigation and sustainable development efforts in developing nations. It allows developed nations to fulfil a portion of their emission reduction commitments by investing in projects that reduce GHG emissions in developing countries. These projects can be implemented wherever emission reductions can be achieved most effectively and efficiently. Solid waste management has tremendous potential to reduce GHG emissions and contribute to carbon credits. The emission reductions achieved by CDM projects are measured using internationally agreed methods and are quantified in Certified Emission Reductions (CERs), which represent a specific amount of greenhouse gas emissions avoided or reduced. CERs can be traded and sold on international carbon markets, providing a financial incentive for emission reduction efforts. In addition, the price of CERs allows waste

[17] Ministry of Power & Ministry of Environment, Forests & Climate Change to develop Carbon Credit Trading Scheme for Decarbonisation. (n.d.). Pib.gov.in. Retrieved July 5, 2023, from https://pib.gov.in/PressReleasePage.aspx?PRID=1923458

sector projects to potentially recoup between 50 to 100 per cent of their capital costs through the sale of carbon credits[18].

Globally, carbon markets are classified into two categories, i.e., voluntary and compliance markets. Both serve the purpose of mitigating carbon emissions. In voluntary markets, companies have the option to reduce their carbon emissions as they see fit, without any legal requirement to do so to contribute to environmental improvement. On the other hand, in compliance markets, companies are legally mandated to decrease their emissions. In the Indian context, the establishment of a compliance market can be facilitated through efficient solid waste management, where companies can generate carbon credits by recycling or processing the waste. The market can yield significant outcomes for creating environmental sustainability. For instance, the Government could establish a compliance standard mandating that companies recycle a percentage of their waste through an efficient recycling system. Usually, this market functions via a cap-and-trade system. Here, emission limits are established by authorities, defining the maximum allowable level of emissions. Companies/firms must ensure that their emissions stay within these set limits. Those unable to meet this compliance have to pay a penalty. In cases where the components over-comply or recycle a greater proportion of waste, they can earn carbon credits for it. So, any company that is not able to meet the compliance requirements can buy credits from other companies at a price. This can lead to a market for credits, and the revenue from selling the credits can be an incentive for the firms to recycle a higher percentage over the compliance standard.

The Okhla composting plant project exemplifies an integral role of the CDM in promoting the sustainable operation of waste reuse ventures while simultaneously combatting climate change. This facility annually converts approximately 73,000 tons of municipal solid waste (MSW) into compost, demonstrating significant potential for waste management in mitigating greenhouse gas emissions, and it averts around 1,600 tons of methane (equivalent to 34,000 tons of CO2) emissions per year[19]. Furthermore, the compost produced serves as a sustainable alternative to chemical fertilisers. Similarly, in Morocco, a number of new landfills have been developed, and existing landfills have been rehabilitated by capturing biogas produced by solid wastes[20]. It is done to encourage the utilisation of landfill gas (LFG) through flaring or conversion into energy, helping in mitigating GHG emissions. This initiative aims to encourage investment by creating a source of revenue for municipalities or private operators of landfills. They can achieve this by selling carbon credits generated through the program. According to a study by the Food and Agriculture Organization of the United Nations (2017), food waste emitted about 9.3 billion tonnes of CO2e (GtCO2e). The global food system is responsible for around one-third of all the greenhouse gases emitted each year[21]. As a result, when the food wastes end up in landfills, it releases methane. A Miami-based climate tech company, CoreZero prevented 221,800 tons of carbon emissions that have been transformed into carbon credits.

- **Utilising technological innovations in disposal methods**

[18] What is climate change and the Kyoto Protocol? (n.d.). Retrieved March 9, 2024, from https://www.ccacoalition.org/sites/default/files/resources//UN%20ESCAP%20-%20factsheet%20-%20Carbon%20Financing%20and%20Solid%20Waste%20Management.pdf

[19] Gebrezgabher et al., (n.d.). Section III: Nutrient and organic matter recovery 391 case: Solid waste composting with carbon credits for profit (IL&FS, Okhla, India). Taylor & Francis Online. https://www.iwmi.cgiar.org/Publications/Books/PDF/resource_recovery_from_waste-391-399.pdf

[20] Generating Carbon Credits From Landfills in Morocco. (n.d.). World Bank. Retrieved March 9, 2024, from https://www.worldbank.org/en/results/2015/10/13/generating-carbon-credits-morocco

[21] L, J. (2023, March 14). Turning 1.3 billion tons of Food Waste into Carbon Credits. Carbon Credits. https://carboncredits.com/turning-1-3-billion-tons-of-food-waste-into-carbon-credits/

Different regions have varying compositions of waste based on cultural, economic, and lifestyle factors. The technology that is selected must be well-suited to handle the specific characteristics of waste generated in a particular region. In the Indian context, some of the common materials found in the waste typically include organic matter, plastics, and other recyclables. Therefore, the chosen technology should be standardised, meaning it follows established norms and guidelines for waste management. Additionally, it should also be assessed from a life cycle cost perspective, which involves considering costs associated with the technology over its entire life span, including initial investment, operation and maintenance, and eventual decommissioning. Choosing a technology with the lowest life cycle cost ensures economic viability and sustainability. The technology should be scalable to accommodate the growing waste generation in the future. As populations and urbanisation increase, waste generation is likely to rise as well. Therefore, the chosen technology should have the flexibility to be expanded or modified to meet the increasing capacity requirements efficiently. In addition, adherence to international emission standards is crucial for environmental sustainability. The selected technology should ensure that the waste management processes comply with global emission standards to minimise environmental impact and prevent harm to human health.

Technology is a major source of opportunities for improving data quality and monitoring the operations of the solid waste management sector. As a country, India still lags behind in adapting to technological advancements, and there is a need for technology penetration in the collection, disposal and treatment of solid wastes[22]. The amount of waste generated and the characteristics of waste play crucial roles in determining the most suitable disposal technology. By analysing waste quantity, it becomes possible to estimate the infrastructure requirements accurately as well. Regular waste analysis is important to monitor changes in waste characteristics, considering the dynamic nature of waste generation. This data not only informs decision-making but also provides a basis for upgrading or transitioning to more effective disposal or treatment methods such as waste to energy, recycling, composting, etc. By understanding the composition and quantity of waste generated, decentralised disposal facilities can be formulated accordingly. This strategic approach is expected to further alleviate the pressure on landfills and reduce overall expenditure. Decentralised disposal facilities would offer localised solutions for waste management, ensuring that waste is processed closer to its source. This approach not only minimises transportation costs but also reduces the strain on centralised landfill sites. Additionally, it allows for more targeted disposal methods based on the types and volumes of waste generated in specific areas, thus promoting a more sustainable and cost-effective waste management system.

Landfills - They are primary dumping sites for waste. Studies have found that these landfills emit methane when organic wastes, such as food scraps, wood, paper, etc., start decomposing in the absence of oxygen. Methane is regarded to trap 86 times more heat in the atmosphere than carbon dioxide over a 20-year period, and this feature makes methane a significant target for climate mitigation efforts[23]. Landfills pose severe health risks to the population; on one hand, the foul odour emerging from the towering waste heaps fills the air and pollutes it, while the leachate seeping from the garbage contaminates underground water sources. Scientists also warn that emissions from unmanaged landfills have the potential to double by 2050[24], driven by the

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[22] Tewari, S. (2021, February 25). Why India's solid waste management system needs a digital overhaul. Www.downtoearth.org.in. https://www.downtoearth.org.in/blog/waste/why-india-s-solid-waste-management-system-needs-a-digital-overhaul-75671

[23] Carrington, D., Clarke, S., editor, environment, & editor, visual projects. (2024, February 12). Revealed: the 1,200 big methane leaks from waste dumps trashing the planet. The Guardian. https://www.theguardian.com/environment/2024/feb/12/revealed-the-1200-big-methane-leaks-from-waste-dumps-trashing-the-planet?CMP=Share_iOSApp_Other

[24] Carrington, D., Clarke, S., editor, environment, & editor, visual projects. (2024, February 12). Revealed: the 1,200 big methane leaks from waste dumps trashing the planet. The Guardian.

increasing urban populations. According to an analysis of satellite data by Kayrros from 2019 to 2023, the Ghazipur landfill in Delhi stood out as one of the major sources of methane emissions and especially in summers the production of methane increases which leads to the accumulation of trapped methane within the layers of the landfill and this can potentially ignite fires[25]. Since 2020, Delhi has experienced a minimum of 124 events of super-emission originating from its city landfills[26]. The escalation in methane emissions poses a significant threat, greatly diminishing the likelihood of averting climate catastrophe. As such, addressing methane emissions from landfills is crucial in the global effort to combat climate change and mitigate its adverse effects.

As per a study by Gupta et al., (1998), landfills need to be designed with leachate collection, gas monitoring and collection systems. In a similar way, Balasubramanian (2018) highlights that the development of an appropriate landfill technology requires reinvention, including several alternatives for mitigating greenhouse gas emissions. Increasing the depths of the landfill to about 9-10 meters is the most important, and this adjustment has two purposes, i.e., to facilitate proper anaerobic conditions essential for methane generation and to ensure that the methane produced reaches a sufficient volume for subsequent collection and utilisation. It is imperative that pretreatment methods before landfilling undergo thorough testing and adaptation to local conditions. Factors such as waste composition and climatic variations must be carefully considered to optimise the effectiveness of pretreatment processes. Landfilling should only be permitted for waste that cannot degrade, such as inert materials, and for other waste that is not suitable for recycling or biological processing. Various technological solutions are being explored to convert municipal solid waste (MSW) into energy or value-added products, aiming to reduce the burden on landfills. Low Carbon Technology (LCT) stands out as a promising approach, playing a crucial role in curbing carbon dioxide emissions, and it is specifically significant in the Indian context, as LCT not only decreases reliance on fossil fuels but also emphasises the utilisation of renewable resources (Mohapatra, 2020).

- **Public-private partnerships**

Private sector participation in the implementation of services related to solid waste management has the potential to provide abundant results if utilised in an appropriate manner. This collaborative approach can be applied across various facets of waste management, such as segregation, door-to-door collection, transportation, proper disposal and treatment, etc. By engaging PPP, municipalities and local bodies can leverage the expertise, resources, and innovation of the private sector to address the complexities of waste management effectively. Public-private partnership arrangements can provide the required momentum for bridging the gaps in infrastructure and operational capabilities, thereby improving the overall efficiency of solid waste management. In addition, long-term contracts, guaranteed waste supply agreements, preferential leasing terms for land, and payment mechanisms such as tipping fees can incentivise private sector involvement (CPHEEO, 2013). Furthermore, regulatory reforms and amendments

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https://www.theguardian.com/environment/2024/feb/12/revealed-the-1200-big-methane-leaks-from-waste-dumps-trashing-the-planet?CMP=Share_iOSApp_Other

[25] Decline in large fires at Delhi's garbage mountains, shows data. (2024, February 23). Hindustan Times. https://www.hindustantimes.com/cities/delhi-news/decline-in-large-fires-at-delhi-s-garbage-mountains-shows-data-101708712602216.html

[26] Carrington, D., Clarke, S., editor, environment, & editor, visual projects. (2024, February 12). Revealed: the 1,200 big methane leaks from waste dumps trashing the planet. The Guardian. https://www.theguardian.com/environment/2024/feb/12/revealed-the-1200-big-methane-leaks-from-waste-dumps-trashing-the-planet?CMP=Share_iOSApp_Other

to municipal bye-laws are essential to provide a clear legal framework for private sector participation in waste management.

Approvals are a major hindrance to the success of private projects. For instance, to put up a waste to energy project, 14 government approvals from different entities are required to be taken by the private developer[27]. Usually, delays and cost overruns are common challenges in the implementation of any public-private partnership initiatives. Therefore, to reduce these risks and ensure seamless execution of the project, it is important to address barriers and uncertainties. As an effective enabler, the project owner, i.e., the government entity, should undertake the responsibility of obtaining all necessary approvals before initiating the bidding process. By frontloading the approval process, the project owner can significantly de-risk the project, and this approach can further minimise uncertainties for prospective bidders, streamline project timelines, and reduce the likelihood of delays during subsequent phases of implementation. Moreover, by securing approvals beforehand, the project owner demonstrates a commitment to facilitating a conducive environment for PPP investments, thereby instilling confidence among stakeholders and encouraging greater participation in the bidding process. Furthermore, de-risking the project through comprehensive approvals helps mitigate the potential for time and cost overruns. It allows for a more accurate assessment of project requirements, risks, and timelines, enabling bidders to develop realistic proposals and allocate resources effectively.

Way Forward - Concluding remarks

Inadequate handling of Municipal Solid Waste (MSW) poses significant challenges, especially concerning its influence on the expanding population. In April 2022, the city of Delhi released an alarming amount of methane into the atmosphere that reached a staggering rate of 434 tonnes per hour, equivalent to the pollution generated by 68 million petrol cars running all at once[28]. These kinds of incidents are a stark reminder that the issue should not be neglected because it can result in widespread consequences for the environment and public health. Therefore, solid waste management needs to be reshaped by adopting a holistic approach and inculcating a culture of accountability. This transformation requires shifting away from reliance on landfills/open dumps and transitioning towards a circular economy model, where waste is viewed as a valuable resource. Achieving this goal involves a collective dedication from individuals, communities, and organisations. It is critical to educate the public on the significance of their part in reducing the difficulties brought on by the growing amount of MSW. The benefits would lead to a cleaner environment, improved planetary health, and a more sustainable future for generations to come.

Solid Waste Management (SWM) poses a significant challenge in India, especially considering the current per capita waste generation of 0.5 kg, which is projected to rise in the future. Municipal budgets are under pressure, primarily allocated towards employee salaries, leaving limited resources for investing in SWM infrastructure. To tackle these issues, it is crucial to explore financial strategies like increasing property taxes, implementing feasible and viable business models for waste treatment such as composting and waste-to-energy facilities, and engaging the private sector to boost funding for SWM projects. These measures can enhance the financial sustainability of SWM initiatives and contribute to better waste management practices across the country. Integrating private sector involvement will effectively complement state efforts, given the finite or stagnating capability of governmental resources over time. There is no one-size-fits-

[27] This data has been collected from our stakeholder interaction with Climate Circle.

[28] Carrington, D., Clarke, S., editor, environment, & editor, visual projects. (2024, February 12). Revealed: the 1,200 big methane leaks from waste dumps trashing the planet. The Guardian. https://www.theguardian.com/environment/2024/feb/12/revealed-the-1200-big-methane-leaks-from-waste-dumps-trashing-the-planet?CMP=Share_iOSApp_Other

all approach to solving the complex issue of solid waste management; instead, a comprehensive plan is necessary.

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