Municipal Solid Waste Management in India: Policy and Technology Pathways for Climate Action

A Deep Dive Report


GERON

Contents

List of Tables

List of Figures

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Preface

This deep-dive report on waste management, authored by Gateway Research and the Institute for Governance & Sustainable Development (IGSD) with support from IORA Ecological Solutions, presents a comprehensive analysis of India's landfill sector, focusing on the critical intersection of waste, climate change, and public health through the lens of short-lived climate pollutants (SLCPs). India's rapidly growing waste generation, coupled with gaps in scientific disposal, has led to widespread reliance on landfills and dumpsites that emit significant quantities of methane (CH_4), a potent SLCP with a global warming potential (GWP_{20}) of 84 times as compare to that of carbon dioxide (CO_2) over a period of 20 years. These emissions not only exacerbate climate change but also contribute to local air pollution and public health hazards.

Drawing on IGSD and Gateway Research's expertise in climate policy and rapid mitigation of non-CO_2 super-pollutants, including methane, black carbon, and hydrofluorocarbons (HFCs), alongside IORA's practical experience in nature-based and technological solutions such as the India Organic Waste Management Programme (IOWMP), this report explores integrated solutions to address landfill methane emissions and other SLCPs arising from the waste sector. We examine policy frameworks, behavioral drivers, and cutting-edge technologies that can transform waste management practices—from improved segregation and recycling to bio-mining of legacy waste and deployment of innovative biogas technologies.

The report begins by providing a historical overview of waste management in India, tracing its evolution from early composting initiatives in the mid-20th century to the present regulatory landscape shaped by the SBM 2.0 and the Solid Waste Management (SWM) Rules, 2026. It assesses the current waste generation, composition, and disposal practices, highlighting the systemic challenges that perpetuate landfill dependence and associated SLCP emissions.

Key issues addressed include the data limitations that hinder effective tracking of waste flows and methane emissions, technology and capacity constraints within urban local bodies, workforce limitations including the integration of informal waste workers, and enforcement gaps in existing regulations.

Technological pathways discussed include anaerobic digestion, bio-methanation, waste-to-energy conversion, and landfill gas capture systems, all of which can significantly reduce emissions while recovering energy and resources. The report further underscores the potential of circular economy models to minimize landfill dependency and unlock economic and environmental co-benefits, particularly through the promotion of waste segregation, recycling, and Extended Producer Responsibility (EPR) schemes.

By synthesizing scientific data, policy analysis, and field-level case studies, this report aims to provide policymakers, urban local bodies, industry stakeholders, and civil society with actionable insights to accelerate India's transition toward sustainable, climate-resilient waste management. The collaboration between IGSD and IORA represents a unique blend of global climate expertise and ground-level implementation experience, offering a holistic roadmap to mitigate SLCP emissions from landfills and enhance India's environmental, public health, and climate outcomes. This report is intended to serve as a foundational resource to guide national and subnational efforts in addressing the intertwined challenges of waste management, SLCP mitigation, and climate change.

About IGSD

The Institute for Governance & Sustainable Development (IGSD) is an international research and policy organization founded in 2003 and focused on accelerating effective climate solutions to address near-term warming and prevent catastrophic climate and societal tipping points. IGSD works on fast mitigation strategies, especially targeting non-CO_2 climate pollutants and self-reinforcing climate feedback that contributes significantly to global warming.

Since its inception in May 2023, IGSD's India Program spearheads initiatives for the rapid mitigation of non-CO_2 climate super-pollutants. This program focuses on reducing emissions of short-lived climate pollutants such as methane, black carbon, and hydrofluorocarbons (HFCs), which have high warming potential, but shorter atmospheric lifetimes compared to CO_2. The India Program collaborates with government agencies, industry, and civil society to implement policies and technologies that can quickly reduce these emissions and deliver near-term climate benefits.

IGSD also produces extensive research and policy publications, providing scientific and technical resources to support governments and stakeholders in designing and implementing effective climate mitigation strategies across sectors such as refrigeration, waste management, and industrial processes.

In summary, IGSD plays a critical role in:

- Promoting fast-action climate solutions to slow near-term warming.
- Targeting non-CO_2 climate pollutants for rapid mitigation.
- Supporting national and subnational programs, notably in India, to implement sustainable policies.
- Providing technical guidance and capacity building through research and resource guides.

This work complements broader sustainable development and climate goals by addressing some of the most potent and immediate contributors to climate change.

About Gateway Research

Gateway Research is a science-first research and policy institute dedicated to advancing evidence-led solutions for sustainable development, climate resilience, and economic transformation. Incubated at the Institute for Governance & Sustainable Development (IGSD), the institute bridges the gap between cutting-edge scientific research and policy implementation, translating complex data into actionable strategies for governments, businesses, and development partners.

Gateway Research brings together a multidisciplinary team of policy researchers, economists, atmospheric scientists, geospatial analysts, and data scientists to address some of the world's most pressing environmental and development challenges. Its work combines advanced scientific modelling, emissions inventories, artificial intelligence, economic analysis, and policy research to deliver practical, evidence-based recommendations that accelerate near-term climate action and strengthen long-term resilience.

The institute's expertise spans climate and air quality, sustainable cooling, climate economics and finance, governance and public policy, artificial intelligence and scientific modelling, and technical advisory services. Through close collaboration with national and sub-national governments, international organisations, financial institutions, and industry, Gateway Research supports the design and implementation of policies, investment strategies, and institutional frameworks that promote sustainable and inclusive development.

Guided by a commitment to scientific excellence, interdisciplinary collaboration, and measurable impact, Gateway Research seeks to transform rigorous research into practical solutions that inform decision-making, strengthen institutions, and enable a more sustainable future.

Glossary

Term / Acronym	Definition
Anaerobic Digestion/ Biomethanation	A biological process in which microorganisms decompose organic materials, such as food waste, agricultural residues, and manure, in the absence of oxygen, producing biogas for renewable energy and digestate, a nutrient-rich fertiliser.
Centralized Waste Management	A unified system where municipal bodies or professional contractors collect, transport, and process waste at large-scale, off-site facilities. It relies heavily on extensive transportation networks and high-capacity infrastructure to manage city-wide garbage, recycling, and sewage
Circular Economy	An economic model that emphasizes minimizing waste generation and maximizing the reuse and recycling of resources.
Decentralized Waste Management	An approach that promotes **source segregation** and localized, small-scale processing of waste (like composting or biomethanation) within or near communities to reduce the volume of waste transported to landfills.
Dumpsite Remediation Accelerator Programme (DRAP)	An initiative to fast-track remediation of 214 legacy waste dumpsites which account for 80% of the remaining legacy waste and reclaim land for productive urban use, while preventing creation of new dumpsites by September 2026. DRAP covers 200 Urban Local Bodies (ULBs) for 100% remediation of 214 most difficult dumpsites across the States and Union Territories.
Dumpsite	An **unregulated** and **unmanaged** area where waste is simply dumped without scientific design, leading to high environmental impact and significant public health risks.
EPR (Extended Producer Responsibility)	A regulatory requirement compelling producers, importers, and brand owners to take responsibility for managing the post-consumer life cycle of their products, particularly for plastic and e-waste, including their collection and recycling.
Legacy Waste	Aged **Municipal Solid Waste (MSW)** that has accumulated over years in unsanitary dumpsites and landfills due to a lack of proper treatment and disposal.
MRF (Material Recovery Facility)	A specialized facility used for the sorting, processing, and baling of dry waste to recover recyclable materials. They are often localized and decentralized to improve efficiency.
MSW (Municipal Solid Waste)	General term for waste generated in urban areas, typically consisting of a mix of compostable organics, paper, plastics, metals, textiles, and other inert materials.
Sanitary Landfill	A **regulated** and **scientifically designed** facility with planned layers and compaction for the controlled disposal of residual waste, engineered to minimize environmental and health impacts.
SBM (Swachh Bharat Mission)	A major government initiative launched in 2014, with **SBM 2.0** (2021) aiming to create a "Garbage Free" urban environment by prioritizing waste segregation and the remediation of legacy waste sites.
SLCPs (Short-Lived Climate Pollutants)	Climate pollutants like **methane**, **black carbon**, and **HFCs** that have a high global warming potential but a short atmospheric lifespan compared to carbon dioxide CO2, making their mitigation an effective way to slow near-term warming.
Solid Waste Management Rules, 2016	A regulatory framework **mandating source segregation** (wet/dry/hazardous), door-to-door collection, and promoting decentralized processing and integration of the informal sector.
Solid Waste Management Rules 2026	Building on the framework established under the SWM Rules, 2016, the, 2026 rules establish[1] a more comprehensive and implementation-oriented approach to waste management, with strengthened provisions for four-stream waste segregation at source, enhanced accountability for Bulk Waste Generators (BWGs), scientific waste processing, improved digital monitoring and compliance mechanisms, and a greater emphasis on climate-responsive waste governance.
Source Segregation	The mandatory and critical practice of separating waste into distinct streams (typically wet, dry, and domestic hazardous) at the point where it is generated (e.g., at the household level).
ULBs (Urban Local Bodies)	The municipal authorities responsible for the overall operation and management of the Solid Waste Management system, including collection, transportation, processing, and disposal.
Waste-to-Energy (WTE)	Technology that converts waste into usable energy, often through processes like incineration or anaerobic digestion. Incineration in India faces challenges due to the low calorific value of the country's MSW.

EXECUTIVE SUMMARY

As India charts its pathway to net zero, the waste sector demands far greater attention. India reports approximately 14.6% of national methane emissions—second only to agriculture—it is a growing contributor to near-term warming. Despite this, its mitigation potential remains underleveraged. Addressing waste emissions could unlock some of the most immediate and high-impact climate gains available to the country.

Current Scale of the Problem:

India generates nearly 170,000 tonnes of municipal solid waste (MSW) daily, yet only about 100,000 TPD (≈61%) is processed, while around 38,000 TPD (≈22%) is transported to disposal sites, leaving a large share outside the formal processing stream. This gap sustains reliance on open dumpsites and poorly managed landfills spread across over 15,000 acres and holding more than 2,700 lakh tonnes of legacy waste, which function as persistent and largely uncontrolled sources of non-CO_2 emissions. A major contributor is methane, a SLCP that is 84 times more potent than CO_2 over a 20-year period, generated through the anaerobic decomposition of organic waste—which constitutes 40–70% of India's waste—primarily at disposal sites. Beyond accelerating near-term warming, methane emissions from dumpsites also intensify urban air pollution, landfill fires, groundwater contamination, and public health risks. At its core, the problem stems from an unoptimized waste value chain that continues to prioritize disposal over recovery, compounded by minimal landfill gas capture and weak operational controls.

Purpose and Scope of This Report:

This report, ***Municipal Solid Waste Management in India: Policy and Technology Pathways for Climate Action*** examines India's waste sector through a near-term, high-impact mitigation lens. It analyses how growing waste complexity, persistent gaps in segregation and processing capacity, and inadequate landfill management are driving avoidable methane emissions. The report evaluates the policy, technological, financial, behavioural, and institutional interventions required to reverse current trajectories and reposition waste management as a climate mitigation and resource recovery opportunity. Using emission inventories, scenario modelling, and implementation roadmaps, it quantifies how alternative waste pathways can significantly reduce methane emissions from dumpsites and landfills while delivering co-benefits for air quality, urban resilience, and energy recovery.

To guide this analysis, the report follows an **"hourglass" structure** (Figure 1). It begins with a broad assessment of India's municipal solid waste sector—covering the evolution of policies, waste generation patterns, governance structures, and the functioning of the waste management value chain. The analysis then narrows to the core issue of methane emissions from dumpsites and landfills, examining their scale, drivers, and data limitations. From this focal point, the report expands outward to assess the wider ecosystem shaping landfill outcomes—including infrastructure, finance, policy, technology, judicial oversight, and behavioural dynamics—before presenting two implementation roadmaps. The report concludes with scenario modelling to quantify the methane mitigation potential of alternative waste management pathways and their associated co-benefits.

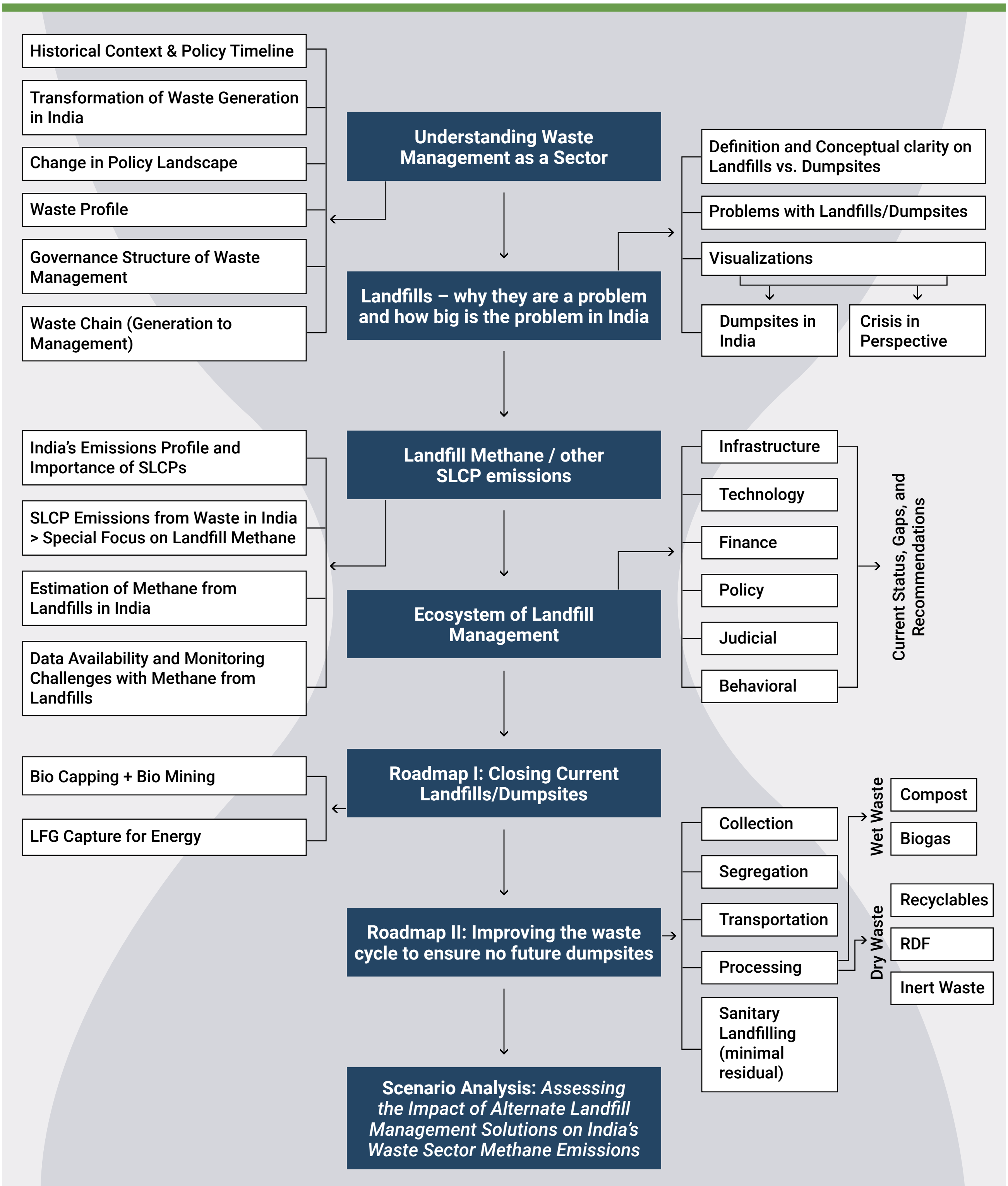

Fig 1. Analytical Framework of the Report

Macro Perspective: Why the problem persists

India's municipal solid waste challenge stems from interconnected gaps across governance, infrastructure, technology, finance, behaviour, and fragmented policies. Rapid urbanisation and changing consumption patterns have increased both the volume and complexity of waste, while waste management systems continue to rely on practices designed for smaller, less heterogeneous streams. Segregation at source remains inconsistent, processing capacity has not kept pace with waste generation, and landfill systems remain inadequate to manage residual waste in a climate-resilient manner.

Although India has established a comprehensive regulatory framework—including the Solid Waste Management Rules (2026) and national programmes such as Swachh Bharat Mission–Urban 2.0—implementation challenges persist. Limited municipal capacity, weak enforcement, fragmented institutional responsibilities, and inadequate monitoring systems have slowed progress. Financing constraints, including limited municipal revenues and restricted access to long-term capital, have further delayed investments in waste processing infrastructure, dumpsite remediation, and methane capture technologies.

As a result, landfills and open dumpsites remain the primary destination for a significant share of India's waste. At these sites, mixed waste decomposes under largely unmanaged conditions, generating substantial methane emissions and other pollutants. Understanding the role of these disposal sites in driving GHG emissions is therefore critical to assessing the waste sector's climate footprint—an issue examined in the following section.

Where the Problem is Concentrated: Emission Hotspots

Waste-sector methane emissions are spatially concentrated, reflecting urbanisation patterns, population density, and the accumulation of legacy waste. Large metropolitan regions with high waste inflows and extensive dumpsites emerge as dominant emission hotspots, or methane plumes. From existing and known knowledge of key large dumpsites in India, the following hotspot identification can be done to identify key dumpsite-based methane plumes in the country (Figure 2):

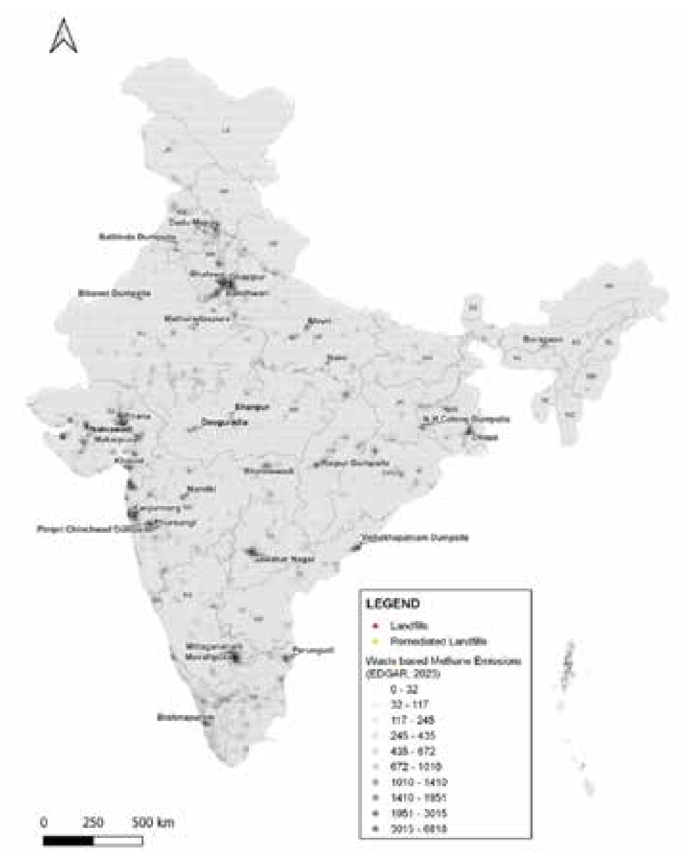

Fig 2. Identified dumpsites and landfills mapped on waste methane plumes (Internal Modelling and Estimation by Report Authors)

The above hotspot identification, while useful, remains insufficient for designing effective ground-level interventions at dumpsites or for informing national and sub-national strategies to reduce the waste sector's climate impact. Addressing methane emissions requires consistent regulatory data, improved monitoring systems, and stronger evidence-based narratives to guide policy and action. A range of tools can support improved methane assessment and management. These include modelling tools such as LandGEM and SWEET for estimating emissions, field measurement methods like surface flux chambers, and analytical frameworks such as IPCC inventory methods. Together, these approaches help quantify, monitor, and manage methane emissions from dumpsites and landfills more reliably.

Along with improved monitoring, modelling, and analytical tools, effective mitigation ultimately depends on systemic interventions across the waste management value chain. Addressing emissions from dumpsites and landfills requires coordinated action across governance, policy frameworks, financing structures, infrastructure development, technological deployment, and public behaviour. The following table presents a high-level summary of the examination of key levers done in this report; highlighting their current status, existing gaps, and priority actions needed to accelerate methane mitigation in India's waste sector (Table 1).

Table 1. Analysis of Various Levers in the Landfill Management Ecosystem

Lever	Current Status	Key Gaps	Priority Recommendations
Judicial	▪ Shift from PIL-led intervention to systemic monitoring ▪ Active role in legacy waste remediation and compliance	▪ Focus on remediation over upstream waste reduction ▪ Reactive compliance culture ▪ No methane-specific benchmarks	▪ Prioritise segregation and decentralised processing ▪ Introduce methane benchmarks in directives ▪ Establish time-bound compliance pathways
Policy & Regulatory	▪ Framework under SWM Rules (2026) and SBM-U 2.0 ▪ Mandates segregation and scientific processing	▪ Weak enforcement and inconsistent penalties ▪ Limited methane monitoring ▪ Circular planning absent in urban design	▪ Introduce tiered national penalties ▪ Strengthen enforcement mechanisms ▪ Mandate methane monitoring and reporting ▪ Integrate MRFs and composting into master plans
Financing	▪ Significant central funding for municipal waste systems ▪ Strong focus on collection and transport	▪ 50–70% spending on collection; <5% on processing ▪ Underutilised funds ▪ L1 tendering discourages innovation	▪ Ring-fence funds for processing infrastructure ▪ Adopt QCBS procurement ▪ Scale PPP models ▪ Mobilise green bonds and carbon finance
Infrastructure	▪ ~54% waste scientifically processed • Biomining addressing legacy dumpsites (~36% remediated)	▪ ~2,400 open dumpsites persist ▪ Limited liners, leachate management, and gas capture ▪ ~46% waste untreated or unaccounted	▪ Accelerate biomining and dumpsite closure ▪ Transition to engineered landfills ▪ Mandate leachate treatment and methane capture
Technology	▪ Biomining widely deployed ▪ WtE plants operational ▪ Emerging LFG capture and biocovers	▪ Limited LFG coverage ▪ Weak waste pre-processing ▪ High capital costs ▪ Limited emissions monitoring	▪ Expand LFG capture via carbon markets ▪ Deploy compost-based biocovers ▪ Strengthen waste pre-processing ▪ Enforce emission standards
Behavioural	▪ Growing awareness through SBM campaigns ▪ Segregation improving in some cities (~50% households)	▪ Public apathy and low risk perception ▪ Awareness gaps ▪ Irregular collection undermines segregation	▪ Scale IEC campaigns ▪ Incentivise household segregation ▪ Ensure reliable collection services ▪ Promote home/community composting

(Based on literature review and stakeholder inputs)

Implementation Roadmaps

Building on the systemic gaps and intervention levers identified in the previous chapter, translating these insights into actionable pathways is essential for reducing methane emissions from India's waste sector. Addressing this challenge requires an integrated approach that tackles gaps at the waste–climate nexus while strengthening waste management systems across the value chain.

In response to the complex policy landscape and performance gaps identified in this report, the study proposes two complementary roadmaps to guide India's response in a structured and scalable manner. Both pathways are anchored in scientific waste management, methane mitigation, and resource recovery, but differ in their sequencing and implementation focus to reflect India's diverse regional contexts.

Roadmap 1 **(Figure 3)** adopts a corrective lens, prioritizing the remediation of legacy dumpsites and existing environmental liabilities. It emphasizes large-scale biomining and bioremediation to excavate and recover materials from accumulated waste, scientific biocapping to safely contain residual fractions, and landfill gas (LFG) capture systems to harness methane for productive use. Beyond emissions reduction, this pathway aims to reclaim degraded land for safe and productive reuse, addressing both historical pollution and near-term climate impacts.

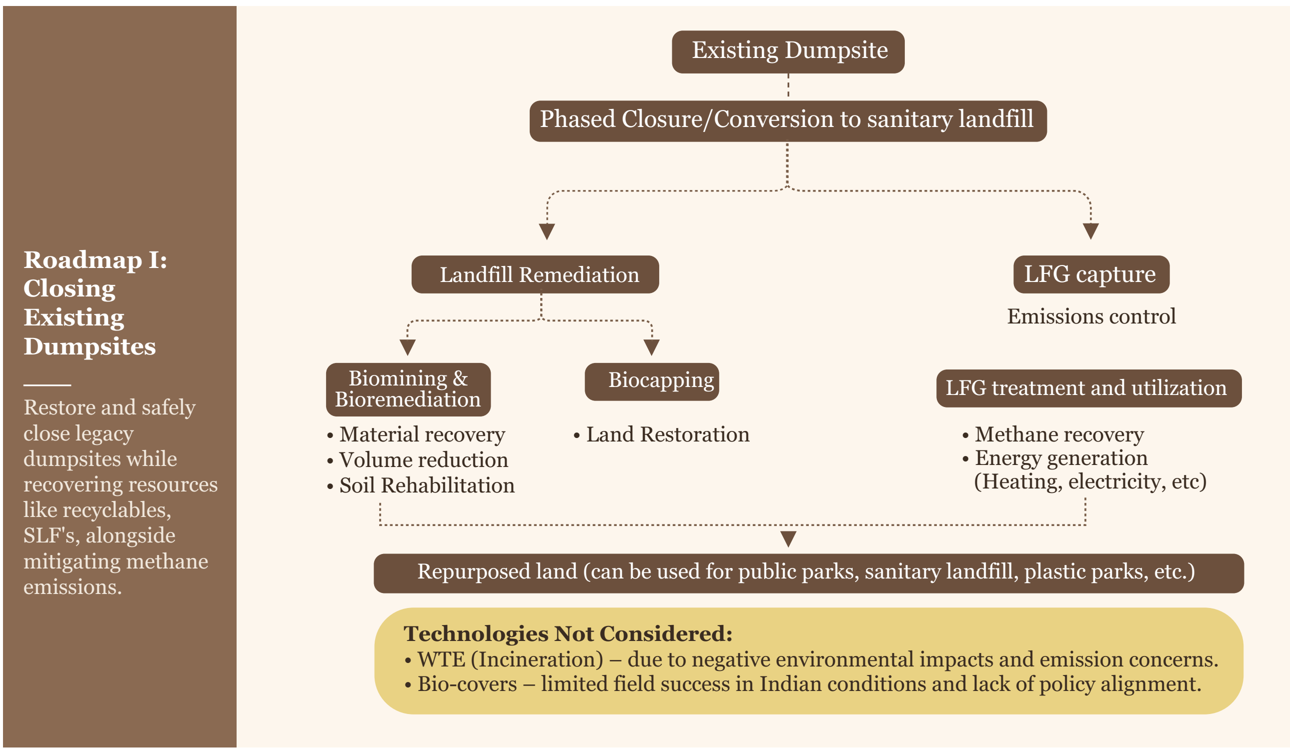

Fig 3. Closing existing dumpsites and landfills

Roadmap 2 (Figure 4), in contrast, is preventative and forward-looking. It seeks to minimize future landfill dependency by enforcing strict source segregation and ensuring direct diversion of waste streams to appropriate processing channels. Based on composition, waste is routed toward recycling, composting, incineration, or waste-to-energy (WtE) facilities, thereby maximizing material recovery and energy generation. This pathway anchors methane mitigation within a broader circular economy transition, reducing landfill inflows while strengthening long-term systemic sustainability.

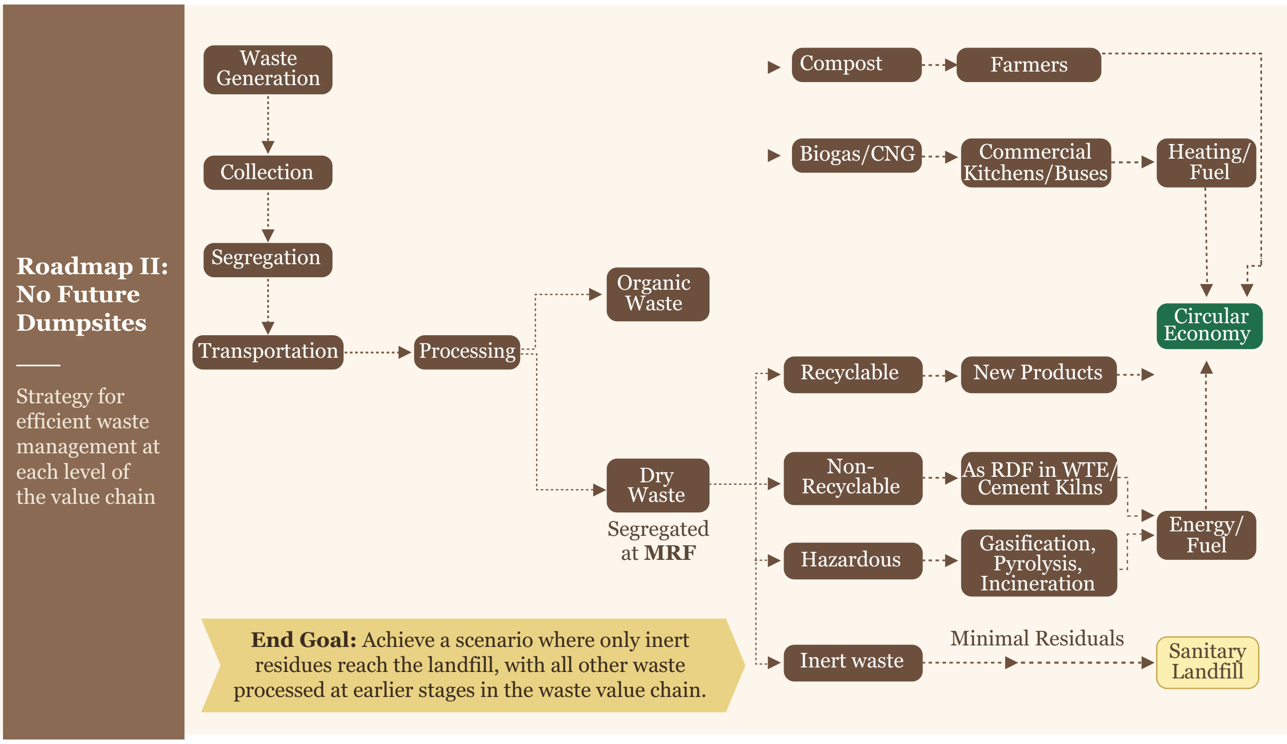

Fig 4. Preventing future dumpsites through the waste value chain optimisation

Scenario-Based Mitigation Pathways

To evaluate pathways for reversing current methane emissions from the waste sector through the recommended roadmaps, the report models three alternative waste management trajectories over 2019–2047, reflecting progressively higher levels of intervention. The scenarios assess the implications of different policy, technological and infrastructure choices for methane emissions, landfill dependence, and long-term system transformation (Table 2).

Table 2. Scenario-based Waste Management Pathways and their Implications for Methane Mitigation

Scenario	Strategic Focus	Core Interventions	Climate Outcome
ALT 1: Legacy Waste + LFG Capture *[Aligned with Roadmap-I]*	Addressing existing emissions sources	Remediation of legacy dumpsites; landfill gas capture and utilisation	Reduces methane from existing dumpsites but does not prevent future emissions
ALT 2: 100% Waste Management *[Aligned with Roadmap-II]*	Preventing future methane formation	Universal segregation; decentralised processing; full treatment of fresh waste	Prevents new methane generation but leaves legacy emissions largely unaddressed
ALT 3: Integrated Approach *[Parallel Implementation of Roadmap I & II]*	System-level transformation	Combination of legacy waste remediation, full waste management reforms, and LFG capture	Delivers largest and fastest methane reductions with sustained long-term impact

Results and Inferences

The modelling confirms that single-point interventions are insufficient. Remediating legacy dumpsites without reforming fresh waste management perpetuates future emissions, while preventing new dumpsites without addressing existing ones leaves major methane sources intact. As evident from the section above, the scenario analysis highlights that India's waste-sector methane trajectory depends on the ambition and integration of policy action. Under Business-as-Usual (BAU), emissions remain largely stable through 2025 and decline only gradually thereafter, with significant emissions persisting even by 2047—reflecting incremental improvements, partial compliance, and continued landfill dependence.

ALT 1 (Legacy Waste Remediation + LFG Capture) delivers a sharp emissions decline between 2025 and 2030 through biomining, biocapping, and methane recovery. However, reductions plateau post-2030, indicating limited long-term momentum without systemic reform.

ALT 2 (100% Organic Waste Management and Diversion) achieves a steadier but sustained decline through nationwide segregation and diversion systems, producing durable mitigation and broader co-benefits.

The analysis concludes that ALT 3 (Integrated Approach)—combining remediation, methane capture, and systemic waste transformation—achieves the fastest and deepest cuts, with emissions nearing zero by 2030.

The Integrated pathway (ALT 3) delivers the largest and fastest methane reductions by combining legacy waste remediation with universal segregation, decentralised processing, and landfill gas capture. Under this pathway, methane emissions from dumpsites and landfills decline sharply over time, while co-benefits accrue across air quality improvement, energy recovery, employment generation, and circular economy outcomes. An integrated pathway is therefore essential to align India's municipal solid waste sector with its SLCP mitigation and climate goals.

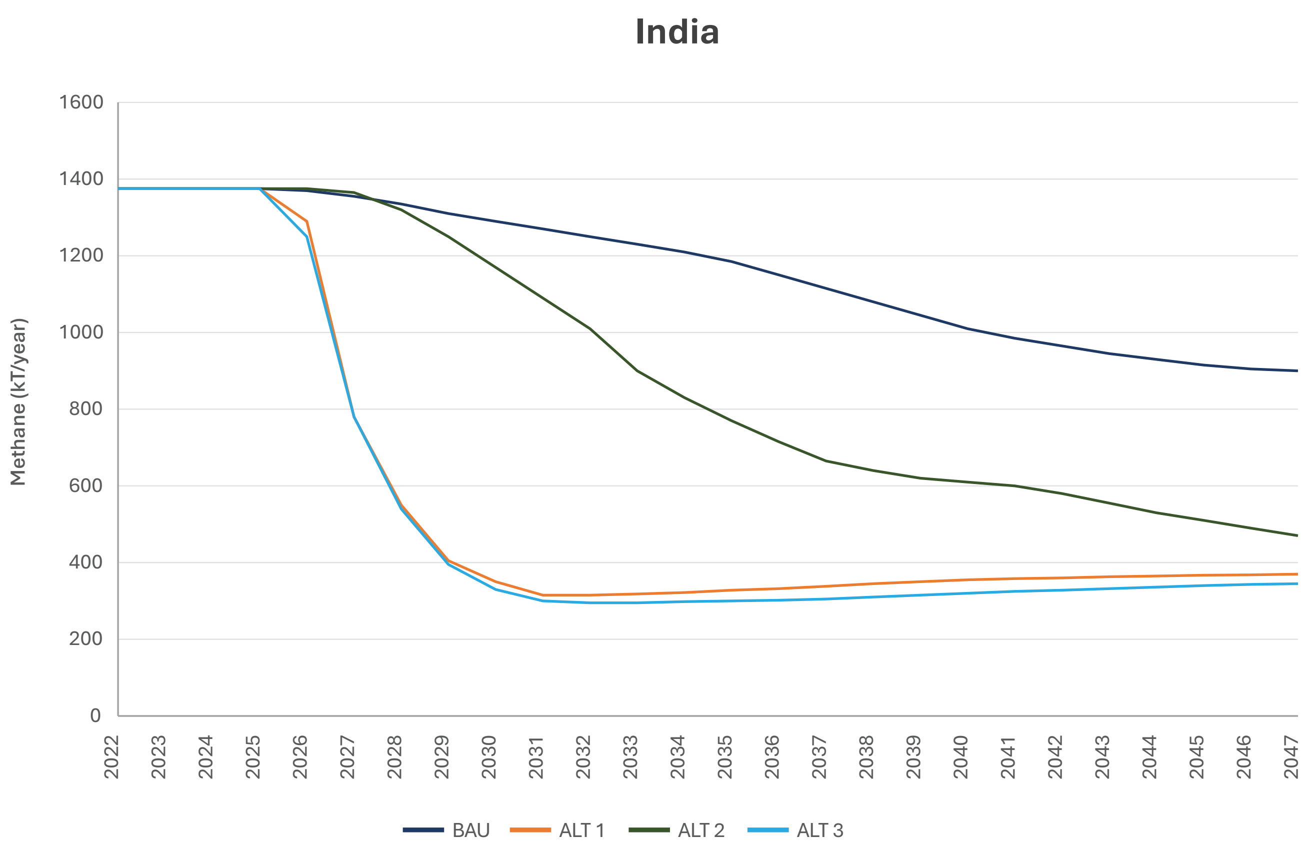

Fig 5. Projected methane emissions from the waste sector under BAU and alternative scenarios, 2019 to 2047

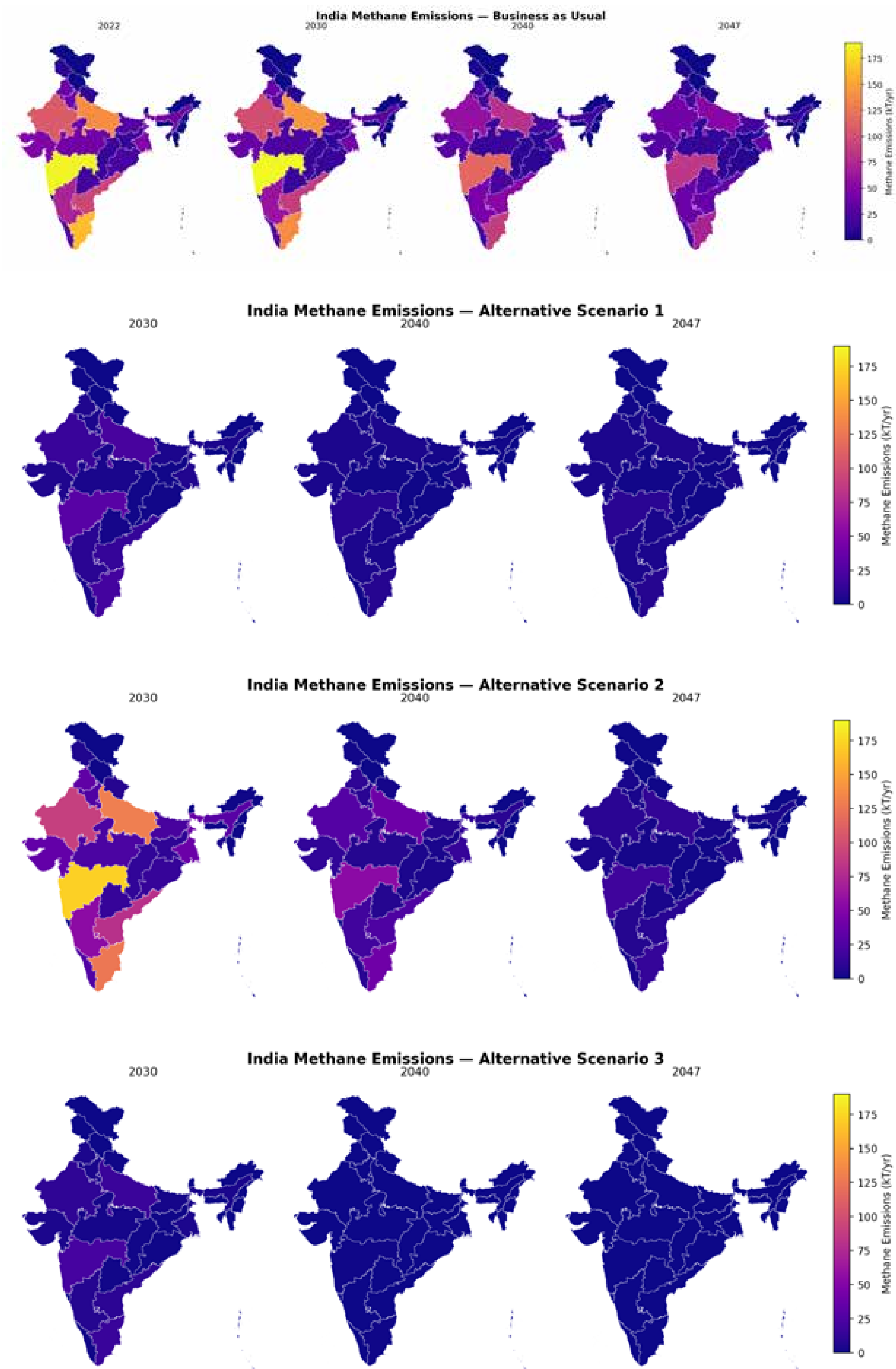

Fig 6. Spatial distribution of methane emissions across India under BAU and alternative scenarios, 2022 to 2047

Conclusively, through its deep-dive into the system, multi-level analysis, emission inventory creation and scenario analysis, this study demonstrates that waste-sector methane mitigation is technically feasible, economically viable, and institutionally achievable within the current decade. Unlocking this potential requires a shift from fragmented, project-based approaches to a coordinated, system-level response that prioritises hotspot cities, aligns financing with methane outcomes, and embeds waste-sector methane mitigation within India's broader SLCP strategy. *Table 3* presents an actionable checklist for stakeholders in the waste management ecosystem to achieve high-impact mitigation in the short term.

Table 3. Scenario-wise Action Checklist for Potential Climate Action

Key Theme	Specific Actions Checklist	Duration	Achievable Reductions in Methane Emissions
Continuing BAU	▪ Gradual improvements in waste management including: • Improve MSW data collection and reporting • Improving source segregation • Enhanced collection capacity • Expansion of waste processing systems ▪ Current trajectory of landfill remediation	Near term (5 years)	Up to 10%
		Medium term (10-15 years)	~35%
		By 2047	~52%
Focus on Landfill and Dumpsite Management (ALT 1)	▪ Accelerated closure/remediation of dumpsites and landfills, in alignment with Lakshya Zero Dumpsite and DRAP targets through: • Mapping key legacy dumpsites • Biomining, biocovers, and remediation of legacy landfills across the country (100% by 2030) ▪ Installation of ground-level methane monitoring systems and LFG capture and utilization infrastructure up to 10% in near term and 20% by 2047	Near term (5 years)	~85%
		Medium term (10-15 years)	~95%
		By 2047	~94%
Optimising the Waste Value Chain (ALT 2)	▪ Strict implementation of source segregation (100% by 2047) ▪ Increased diversion of organic waste away from disposal: • 25% in near term • 75% in medium term • 100% by 2047 ▪ Scale organic waste management infrastructure (composting, biogas, etc.)	Near term (5 years)	~17%
		Medium term (10-15 years)	~73%
		By 2047	~90%
Integrated Waste Management (ALT 3)	▪ 100% remediation of legacy dumpsites and landfills by 2030 ▪ Complete coverage of methane monitoring systems at scientific landfills ▪ 20% LFG capture and utilisation at high potential sites till 2030 ▪ Optimised waste value chain with: • 100% source segregation by 2040s • 70-75% processing of organic waste in the medium term, and 100% by 2047	Near term (5 years)	~90%
		Medium term (10-15 years)	~99%
		By 2047	~100%

Taken together, the findings of this report show that reducing non-CO_2 emissions from India's waste sector is both an urgent climate priority and an achievable opportunity. Emissions from dumpsites and landfills are not an inevitable by-product of urbanisation but the result of systemic gaps in segregation, processing capacity, landfill management, and institutional coordination. Addressing these gaps through targeted interventions—remediating legacy dumpsites, preventing future landfill dependence through universal segregation and waste processing, and deploying methane capture and monitoring systems—can rapidly reduce emissions while delivering co-benefits for air quality, public health, land recovery, and resource efficiency. Scenario analysis indicates that the most effective pathway combines legacy waste remediation with systemic reforms across the waste value chain. By aligning these actions with national climate strategies, India can transform a persistent urban challenge into a powerful lever for near-term climate mitigation and sustainable urban development.

CHAPTER 1:

INTRODUCTION OVERVIEW OF INDIA'S MUNICIPAL SOLID WASTE MANAGEMENT SECTOR

1.1 Tracing the Evolution of Waste Management in India

India's waste story has lurched from compost pits to mountains of plastic. In the 1960s and 1970s, most of the rubbish was organic, and composting was the obvious solution. But dumping—into rivers or on open land—remained the norm. Two disasters changed the script. The Bhopal gas leak in 1984 put hazardous waste on the radar. A plague outbreak in Surat a decade later, further brought attention on municipal waste.[2]

Rules for SWM were introduced in 2000[3], but weak enforcement meant little change. By the 2010s, plastics and electronics had transformed the rubbish heap, while India's cities were running out of space to dump it. The SBM, launched in 2014[4] and updated in 2021[5], finally brought waste into the mainstream of urban reform. Rules in 2016, mandated segregation at source, imposed responsibilities on producers and bulk generators, and promoted decentralised processing.[6] Yet enforcement is patchy, and India still relies heavily on unscientific landfills.

Recognising these gaps, the revised SWM framework introduced in 2026 seeks to strengthen compliance and move India closer to a circular waste economy. The updated rules place greater emphasis on measurable segregation outcomes, stronger accountability for Urban Local Bodies (ULBs) and bulk waste generators (BWGs), expanded producer responsibility (EPR) for packaging waste, and improved monitoring of waste processing and landfill management. They also prioritise the reduction of landfill dependency through enhanced resource recovery, biomethanation, and scientific treatment of organic waste.

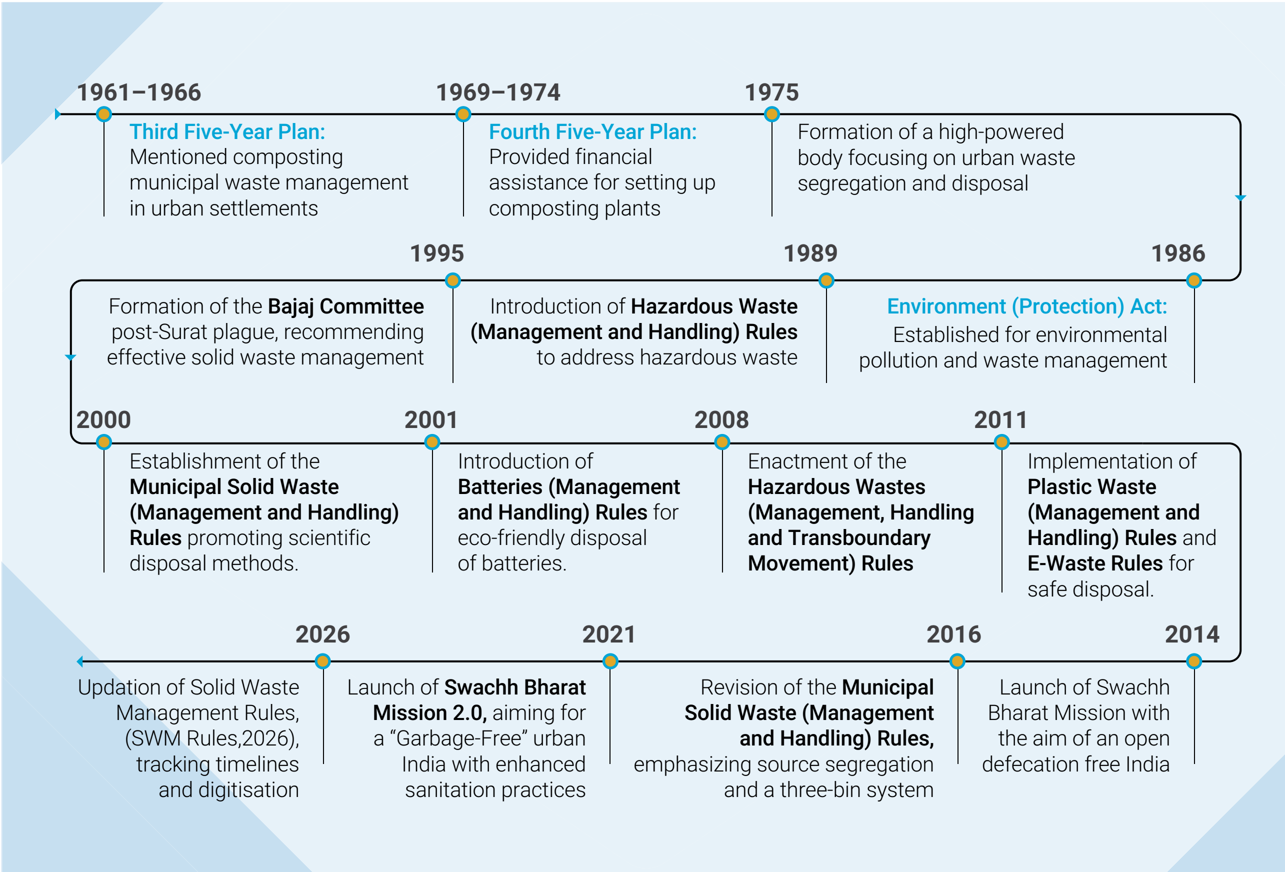

Fig 7. Timeline of policy milestones in waste management in India, 1961 to 2026

1.1.2 Transformation of Waste Generation in India

India's rubbish heap has changed as fast as its economy. For much of the 20th century, urban waste was mostly organic: kitchen scraps, crop residues, and other biodegradable matter. Farmers carted much of it away, composted it, and spread it on their fields.[7i] The system kept cities cleaner and enriched rural soil.

Plastics disrupted that balance.[8] From the 1970s onwards[9], petrochemical advances[10] made plastic cheap and plentiful. Once mixed with organic waste, it clogged fields, reduced soil fertility, and deterred farmers from collecting city discards. Open dumping and unmanaged landfills became the default.

Urbanisation and rising incomes in the 1980s and 1990s added to the mess. More packaging, paper, and consumer goods meant more rubbish. India's municipal solid waste grew from about 48m tonnes in 2008 to 52m in 2016[11], and stood at around 62m as of 2024.[12] Waste-pickers, long the backbone of recycling, continued to recover valuable scraps, but the scale and complexity of the waste stream outpaced them.

The past two decades have brought new streams: 9.3 million tonnes of plastic waste each year[13], 1.6 million tonnes of e-waste, and rising volumes of hazardous, biomedical, and construction debris. Overall waste is projected to reach 165m tonnes by 2030. The share of non-biodegradable and hazardous material is set to climb, compounding the challenge.

India's waste profile has thus shifted from compostable organics to a complex and often hazardous mix dominated by plastics and electronics. Managing it will require not just better segregation at source and the formalisation of the recycling sector, but a significant overhaul of regulation and infrastructure. The revised SWM framework introduced in 2026 attempts to respond to this shift by strengthening segregation mandates, expanding responsibilities for bulk waste generators and producers, and emphasising scientific processing and reduced reliance on landfills. Yet translating these provisions into practice will depend on stronger enforcement, financing, and institutional capacity at the urban local body level.

Table 4: Evolution of Waste Types in India, (pre-1970 to present)

Period	Dominant Waste Types	Key Drivers & Changes	Management Practices
Pre-1970[14]	Organic, ash, paper, textiles. Minimal plastics.	Agrarian society, minimal industrialization. Waste was primarily organic and biodegradable.	On-site composting, feeding to animals. Open dumping was the norm with little formal collection.
1970-1999[15]	Organic, increasing plastics, paper, glass, metals, construction & demolition (C&D) waste.	Rapid **urbanization** and early industrialization. The 1991 economic liberalization increased consumerism and packaging waste.	Open dumping evolved into large, unscientific dumpsites. An extensive **informal recycling sector** emerged to handle valuable waste.
2000-2009[16]	Plastics (significant increase), organic, e-waste, packaging waste.	Economic growth and the "IT boom" increased waste volumes. This period saw the first comprehensive national rules to formalize waste management.	The **Municipal Solid Waste Rules, 2000**, mandated scientific disposal but implementation was slow. The informal recycling sector continued to be the main driver of resource recovery.
2010-2019[17]	Plastics (including single-use), e-waste, C&D waste, complex composite materials.	The **Swachh Bharat Abhiyan (SBM)** of 2014 provided a major push for cleanliness and segregation.	The **Solid Waste Management Rules, 2016**, replaced the previous rules, emphasizing source segregation and **Extended Producer Responsibility (EPR)**. Waste-to-Energy (WTE) plants also gained traction.
2020-Present[18]	Plastics (single-use plastic ban focus), e-waste, medical waste, food waste.	A push for the **circular economy** and government initiatives to ban single-use plastics.	Stricter enforcement of EPR, decentralized processing (composting), and digital solutions for waste tracking. Efforts are being made to formalize the informal waste collection sector through SWM Rules 2026

This overview highlights how the transformation of waste types in India has paralleled economic and social changes, and underscores the urgent need for adaptive, sustainable waste management solutions.

1.1.2.1 Changing Landscape of Solid Waste Management Policies in India

With the change in the amounts and types of waste generated in India over time, there has also been an evolution in the way waste is being managed; causing a profound shift in waste management policies, particularly in addressing legacy waste dumpsites which are essentially unscientific landfills with waste piled over for years. This transformation is exemplified by initiatives like SBM-U 2.0, which has allocated substantial financial resources to enhance source segregation, establish Material Recovery Facilities (MRFs), phase out single-use plastics, process construction and demolition waste, and remediate legacy dumpsites across the country. As India strives to implement a more scientific and sustainable solid waste management system aligned with circular economy principles, it is crucial to overcome the challenges posed by legacy waste.

Policies such as the SWM Rules, 2016, and subsequent[19] regulatory updates have sought to institutionalise this shift. Complementary frameworks like EPR for plastic and e-waste have further expanded accountability across the waste value chain. The updated 2026 rules strengthens these provisions by reinforcing segregation mandates, clarifying responsibilities for ULBs and BWGs, and emphasising improved monitoring of waste processing and landfill management. Together, these policies reflect an increasing recognition that effective waste management requires coordinated action across producers, municipalities, and consumers, given its linkages to air, soil, and water pollution.

- **Centralized vs Decentralized Waste Management**

  Historically, large-scale waste management systems have faced challenges related to high capital investment, operating costs, and the long-distance transport of waste. In response, policy frameworks in India have increasingly emphasized *appropriate scale and proximity-based processing* rather than a strict preference for centralized or decentralized models. The SWM Rules, 2000 encouraged source segregation and composting, while the revised SWM Rules, 2016 explicitly promote processing of waste as close to the point of generation as possible, including through decentralized and ward-level systems where feasible.

Importantly, biological and material recovery processes are not inherently decentralized or centralized in nature. Technologies such as composting, biomethanation, and dry waste recycling can be implemented at different scales, depending on waste quantity, land availability, logistics, and desired economic outcomes. For instance, smaller biogas plants and community composting units are well suited for localized treatment of segregated organic waste, helping reduce transport requirements and the volume of waste reaching landfills. At the same time, larger facilities—such as compressed biogas (CBG) plants and dry waste recycling facilities—often benefit from economies of scale and therefore require aggregation of waste from multiple[20] sources.

The SWM Rules, 2016 established this flexible,[21] integrated approach, encouraging decentralized processing to reduce landfill burden and improve operational efficiency, while allowing centralized or clustered facilities where scale is necessary for technical viability and financial sustainability. Subsequent policy developments, including the updated 2026 framework, have reinforced this principle by placing greater emphasis on measurable segregation outcomes, improved monitoring of waste processing infrastructure, and reduced dependence on landfills. Together, these complementary models enable cities to optimise waste processing, minimise transport burdens, and improve overall system

AN EXAMPLE OF HOW FEROZPUR EXCELLED IN DECENTRALISATION

Ferozepur, a historic city in Punjab, faced challenges in solid waste management with a daily generation of 47 tons of waste. The Municipal Council implemented a decentralized waste management model, including source segregation and door-to-door collection. They established a solid waste management plant and successfully processed 35 tons of waste daily, distributing compost to farmers and selling recyclable materials. Additionally, they creatively reused construction waste and transformed a garbage vulnerable point into a park, promoting public participation and beautification. These efforts improved waste management practices and garnered recognition at the state and national levels.[13]

Here's a table outlining the differences in the processes involved in centralized vs. decentralized waste management in India, focusing on key operational stages:

Table 5: Comparison of Centralised and Decentralised Waste Management in India

Parameter	Centralized Waste Management (India)	Decentralized Waste Management (India)
Governing Framework (2016)	The Solid Waste Management Rules, 2016 were notified by the Ministry of Environment, Forest and Climate Change (MoEFCC) in supersession of the Municipal Waste (Management and Handling) Rules, 2000 (PIB, New Solid Waste Management Rules, 2016).	Under the same 2016 Rules, bulk generators — government organisations, railways, airports, defence establishments, SEZs, hotels, and gated communities above 5,000 sq. m built-up area — were required, in partnership with local authorities, to segregate waste at source and utilize wet waste for composting or bio-methanation on-site (PIB, New Solid Waste Management Rules, 2016).
Governing Framework (2026)	The Solid Waste Management Rules, 2026, notified by MoEFCC, supersede the 2016 Rules and take full effect from April 1, 2026, retaining centralized landfill and disposal infrastructure for residual waste streams (PIB, New Solid Waste Management Rules Notified, 2026).	The revised 2026 Rules mandate four-stream segregation at source and prescribe Extended Bulk Waste Generator Responsibility (EBWGR), requiring bulk generators to ensure their waste is collected, transported, and processed in an environmentally sound manner — a provision expected to significantly reduce the burden on urban local bodies and promote decentralised waste management (PIB, *SWM Rules 2026 to come into effect from April 1,*[22] *2026).*
Digital Monitoring	A Centralised Online Portal, operationalized under the 2026 Rules, tracks all stages of solid waste management — collection, transportation, processing, and disposal — across both centralized and decentralized facilities (PIB, *SWM Rules 2026 to come into effect from April 1, 2026).*	Decentralized/on-site processing facilities established under EBWGR still report into the same centralized portal for compliance and certification purposes (PIB, *SWM Rules 2026 to come into effect from April 1, 2026).*
Fuel Substitution / RDF Utilization	The 2026 Rules prescribe an increase in the fuel substitution rate from the current 5% to 15% over a six-year period for industrial units, including cement plants and waste-to-energy plants using Refuse Derived Fuel (RDF) — a centralized processing pathway (PIB, SWM Rules 2026 to come into effect from April 1, 2026).	Not directly applicable — RDF utilization is inherently a centralized/industrial-scale process under current rules.
Legacy Waste Remediation	The 2026 Rules mandate a time-bound action plan for remediation of legacy waste and further strengthen restrictions on landfilling of solid waste, coordinated at the national/state level (PIB, SWM Rules 2026 to come into effect from April 1, 2026).	In rural areas, the Department of Drinking Water & Sanitation has tasked District Collectors with rural mapping of legacy waste sites and certification by gram panchayats — a decentralized administrative approach to the same remediation goal (PIB, DDWS National Review Meeting on SWM Rules 2026, 2026).
Material Recovery Facilities (Scale)	Larger centralized MRFs are documented for high-population zones — e.g., Chennai's dry-waste MRF model, structured for zones with populations above 10 lakh (MoHUA/Swachh Bharat Mission-Urban, *Advisory on Material Recovery Facility for Municipal Solid Waste).*	The same MoHUA advisory documents smaller-scale, manual MRFs operating at population tiers as low as under 50,000 (e.g., Dungarpur, Rajpura), and defines "decentralized processing" as the establishment of dispersed facilities close to the source of generation to minimize transportation (MoHUA/Swachh Bharat Mission-Urban, *Advisory on MRF for MSW).*
Composting & WtE Technology Guidance	The CPHEEO Manual (2016), published by the Ministry of Housing and Urban Affairs, covers centralized Waste-to-Energy technologies — incineration, biomethanation at scale, and RDF production — as part of its technical guidance for ULBs (MoHUA, Municipal Solid Waste Management Plan: Step-Wise Guidance).	The same CPHEEO Manual provides technical specifications for decentralized composting methods — windrow, aerated static pile, in-vessel, and vermicomposting — as parallel, officially endorsed technologies (MoHUA, Municipal *Solid Waste Management Plan: Step-Wise Guidance).*

Parameter	Centralized Waste Management (India)	Decentralized Waste Management (India)
Circular Economy & EPR Integration	Centralized recycling infrastructure and Material Flow Assessment approaches are addressed in national circular-economy guidance issued by MoHUA, alongside proposals such as a Credit Guarantee Fund to support recycling infrastructure (MoHUA, *Circular Economy in Municipal Solid and Liquid Waste).*	The same MoHUA document notes that without a functioning Extended Producer Responsibility (EPR) framework, circularity — which decentralized recovery models depend on for revenue — cannot be achieved.
Bulk Waste Generator Threshold	Not applicable in the same way — centralized systems handle waste below the bulk-generator threshold through standard ULB collection.	The Ministry of Housing and Urban Affairs defines decentralized processing thresholds relative to average waste generation rates exceeding 100 kg/day from sources such as hostels, hotels, and institutions, at or near the point of generation (MoHUA/Swachh Bharat Mission-Urban, Advisory on MRF for MSW).
Rural Institutional Mechanism	Rural solid waste management was historically less integrated with centralized ULB systems.	Under SWM Rules 2026, the Department of Drinking Water & Sanitation, Ministry of Jal Shakti, has mandated phased implementation of source segregation, identification and registration of bulk waste generators, and certification by gram panchayats as part of Swachh Bharat Mission (Grameen) Phase II (PIB, *DDWS National Review Meeting on SWM Rules 2026, 2026).*
Indigenous Decentralized Technology	Centralized technology procurement has historically relied on capital-intensive imported equipment for large-scale processing.	CSIR-CMERI, a Government of India research body, has developed a Decentralised Solid Waste Management Technology (DSWMT) — a modular, end-to-end solution enabling on-site biogas production, briquetting, and composting, explicitly designed to promote indigenous scientific advancement as an alternative to importing capital-intensive centralized equipment (PIB, CSIR-CMERI develops Decentralised Solid Waste Management Technology).

Addressing Persisting Challenges of Decentralized Systems

Despite these advancements, ULBs continue to face significant challenges, including inadequate funding, infrastructure, and strategies for SWM. This leads to low collection efficiency and uncontrolled disposal. Challenges persist throughout the waste supply chain, from collection to disposal, highlighting the need for continued innovation and policy support to achieve sustainable waste management practices in India.

Addressing these challenges will require a comprehensive approach that integrates technological solutions with community engagement and policy reforms.

Over the past two decades, India's journey in implementing decentralized waste management has yielded numerous best practices and insightful case studies. These experiences serve as valuable learning models to inform and guide future initiatives. Presented below are two such illustrative cases.

In a few select wards of Delhi (e.g., specific areas of East Delhi Municipal Corporation), pilot projects demonstrated decentralized waste management. These involved **promoting household source segregation,** setting up **small-scale composting units** for organic waste, and establishing **mini–Material Recovery Facilities (MRFs)** for dry waste at the ward level. While limited in scale, these initiatives aimed to reduce waste transportation to landfills, recover resources, and improve local sanitation through community involvement.

Key takeaway: Even within a large, centralized system, localized decentralized efforts can effectively reduce landfill burden and promote resource recovery, serving as valuable models for broader adoption.

Kerala has widely implemented a decentralized waste management model across its numerous Local Self-Government Institutions (LSGIs, including Panchayats and Municipalities). The core strategy involves **mandatory source-level treatment of wet waste** (e.g., household composting/biogas plants) and a unique system of **"Haritha Karma Sena" (Green Army)** – women's self-help groups collecting user fees for segregated non-biodegradable waste. This waste is then channeled to Material Collection Facilities (MCFs) for recycling.

Key takeaway: Strong policy support, community empowerment (especially women's groups), and emphasis on source-level treatment can lead to significant waste diversion, improved livelihoods, and cleaner environments, as seen in Kerala's widespread success.

In addition to decentralized solutions, alternative waste management strategies such as WTE plants, bioremediation, and engineered landfills are also being explored to address these gaps occurring individually at the centralised or decentralised level. Therefore, integration of these strategies into one of the approaches at suitable scales can help mitigate environmental degradation by providing more sustainable disposal methods. For instance, WTE plants can convert waste into electricity, reduce landfill waste, and generate energy. Bioremediation techniques use biological agents to clean pollutants from contaminated sites, while engineered landfills are designed with liners and leachate management systems to prevent environmental contamination.

1.2 India's Waste Profile

1.2.1 Composition and Types

India's diverse landscape presents a complex municipal solid waste management challenge, with distinct waste compositions across urban, peri-urban, and rural areas.[23]

Urban centers generate the **highest volume of MSW,** characterized by a significant proportion of dry recyclables like plastics, paper, and packaging, alongside a substantial organic component from diverse food waste. Per capita waste generation in large Indian cities can exceed 0.5 kg/day.[24,25]

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Peri-urban areas exhibit a **hybrid waste profile.** While increasingly adopting urban consumption patterns, leading to more plastics and mixed waste, they also retain a notable proportion of organic waste from agricultural and animal husbandry activities. Rapid, often unplanned development in these zones strains nascent waste management infrastructure.[26,27]

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In **rural settlements,** waste generated is increasingly becoming an issue of serious concern. Though, solid waste generated in rural areas is predominantly organic and biodegradable, it is becoming a major problem as the waste generated is not segregated in-situ and is of the order of 0.3 to 0.4 million metric tons per day, as reported the Ministry of Drinking Water and Sanitation (MDWS), Government of India.[28,29]

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This heterogeneity necessitates localized strategies, as uniform solutions are ineffective. While some ULBs have advanced in waste characterization and tailored plans, many in peri-urban and rural areas lack the technical and institutional capacity for such localized approaches. Recent policy frameworks—including the SWM Rules, 2016 and subsequent updates to the regulatory framework in 2026[30]—recognize this diversity by encouraging context-specific waste processing systems, improved segregation, and stronger planning at the urban local body level. Strengthening on-ground understanding and enabling such localized strategies remain crucial for sustainable waste management nationwide. Building on the distinct waste profiles discussed earlier, a study featured in the Journal of Urban Management (December 2021) provides a national overview of India's waste generation. Out of the staggering 62 million tonnes (MT) of waste generated annually, the study identifies significant proportions of specific waste types: 7.9 MT of hazardous waste, 5.6 MT of plastic waste, 1.5 MT of e-waste, and 0.17 MT of biomedical waste. These figures highlight the scale of specialized waste streams that further complicate localized waste management efforts across India's urban, peri-urban, and rural landscapes.[31]

Building on the understanding of India's diverse waste landscape, Table 2 provides a critical breakdown of the various waste types and their typical compositions. MSW stands out, with **40-60% consisting of compostable organics,** highlighting a significant opportunity for composting and biogas generation. The remaining MSW comprises valuable dry recyclables such as paper, plastics, metals, and textiles, along with inert materials. Beyond MSW, the table identifies more specialized and often hazardous waste streams, including **chemicals and heavy metals in Hazardous Waste, electronic components in E-Waste, biomedical waste like syringes and discarded medicines, and a substantial category of Plastic Waste (PET bottles, bags, packaging), alongside Construction & Demolition waste (concrete, bricks, wood).**

Following this breakup we have, Table 3 emphasizing a critical challenge: a substantial portion of this waste, particularly the organic fraction of MSW, is currently mismanaged through environmentally damaging practices like **open burning or indiscriminate disposal in landfills, dumpsites, and along roadsides.** This unmanaged organic waste is

Table 6: Categories of waste identified by the CPCB and their typical composition[32]

Type of Waste	Typical Composition
Municipal Solid Waste (MSW)	40-60% compostable organics, 6% paper, plastics, metals, textiles, and inert materials.
Hazardous Waste	Chemicals, heavy metals, solvents, and other dangerous substances.
E-Waste	Circuit boards, batteries, plastics, and other electronic components.
Biomedical Waste	Syringes, bandages, discarded medicines, and biological materials.
Plastic Waste	PET bottles, plastic bags, packaging materials, and other plastic items.
Construction & Demolition Waste	Concrete, bricks, wood, metals, and other debris from construction activities.

a major contributor to methane emissions, a potent GHG. Furthermore, the table stresses that high-value materials within MSW, such as paper, recyclable plastics, and metals, are frequently lost to such disposal methods instead of being recovered and reintegrated into a circular economy. The overarching inference is clear: to transition towards sustainable waste management, India must move away from its current linear "take-make-dispose" model. A well-established system incorporating **source segregation** is crucial, as it would enable each distinct waste segment – from compostable organics to various recyclables and hazardous materials – to be processed and transformed into valuable economic resources, mitigating environmental harm and fostering a circular economy. Recognising this, regulatory frameworks such as the SWM, 2016 and subsequent updates in 2026[33] place strong emphasis on mandatory source segregation, improved material recovery infrastructure, and reduced reliance on landfills to enable resource recovery across waste streams.

Table 7. Generation, Processing and Disposal of Different Waste Streams in India

Stream	Fraction of total waste (%)	Quantity of waste generated* (TPD)	Processed or disposed by	Quantity of waste processed/ disposed** (TPD)
Organic waste	40–60	75,000–80,000	▪ Composting (individual, community, windrow, mechanical) ▪ Biomethanization (small and big)	17,000–20,000
			▪ **Dumped in landfills,** dumpsites or roadsides as mixed with other waste fractions	55,000–60,000
Paper, cardboard	6–7	8,000–9,000	▪ Recycling in the paper industry ▪ Waste to energy (WTE)	2,000–2,500
			▪ **Dumped in landfills,** dumpsites or roadsides as mixed with other fractions of waste ▪ Open burning	6,000–7,000
Recyclable plastic (PET, HDPE, PP, etc.)	5–10	9,000–10,000	▪ Refuse-derived fuel (RDF) ▪ Used in road making ▪ Co-pressing in cement kilns ▪ WTE	3,000–4,000
			▪ Dumped with mixed waste ▪ Open burning/ground levelling	4,000–5,000
Metal (tin, aluminum, iron etc.)	1	1000-1500	▪ Recycled ▪ Dumped with mixed waste	-

Stream	Fraction of total waste (%)	Quantity of waste generated* (TPD)	Processed or disposed by	Quantity of waste processed/ disposed** (TPD)
Glass (glass bottles, mirrors, glassware)	1	1000-1500	▪ Recycled ▪ **Dumped with mixed waste**	-
Domestic hazardous waste (batteries, expired medicines, paint containers, tube lights etc.)	1-3	1,000–3,000	▪ Sent to Treatment, Storage and Disposal Facility (TSDF) or Common Biomedical Waste Treatment Facility (CBMWTF) ▪ Lead acid batteries sent for recycling ▪ **Dumped with mixed waste** ▪ Open burning	-
Sanitary waste (sanitary pads, diapers etc.)	0.2–0.4	300–500	▪ Sent to a CBMWTF for incineration ▪ **Sent to dumpsites/landfills** ▪ Open burning	-
Textile waste (cotton, khadi, polyester)	3–5	4,000–5,000	▪ Recycled and resold in markets ▪ WTE/RDF ▪ **Dumped with mixed waste**	-
Rubber (tyres etc.)	1–2	3000 (Close to 275,000 tyres)***	▪ Reused and recycled ▪ Pyrolysis for fuel recovery ▪ **Dumped and open burning** ▪ Refurbished	-

** Approximation based on the MSW generation figure at 52 million tonnes per day, ** Based on data from government reports and estimations, *** Data from Chintan, 'Circulating tyres from economy'.[34]*

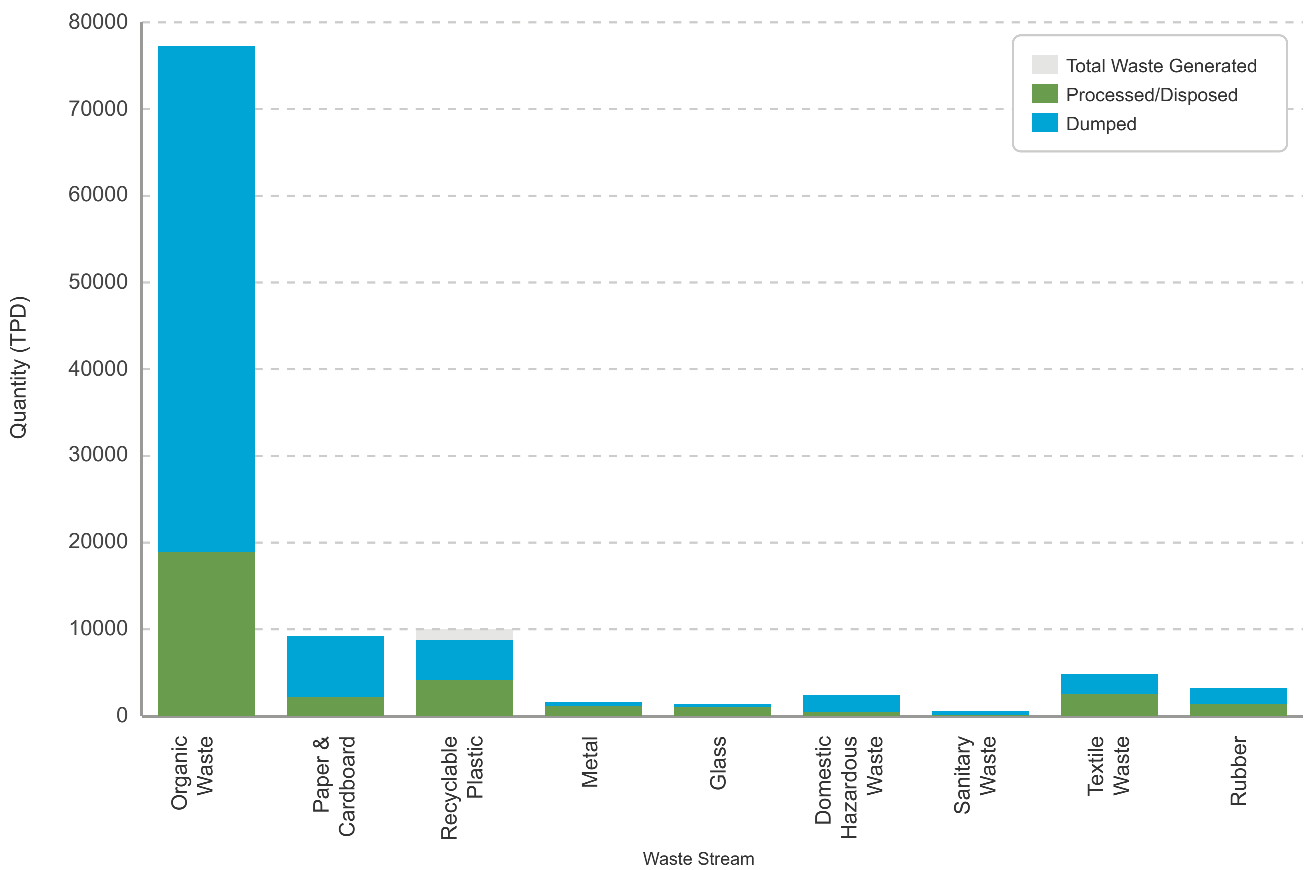


Fig 8. Generation, processing and disposal of different waste streams in India (Source: Centre for Science and Environment)

1.2.2 Current State of Waste in India

According to projections, total waste generation globally is expected to reach **3.4 billion tons by 2050,** a 69% rise from 2016 levels.[35,36] India, urbanization grew from 27.8% to 31.6% between 2001 and 2011, and by 2030, the urban population is projected to reach 630 million. As a result, India is the fastest-growing country in South Asia, with waste generation projected to triple by 2050. On a global scale, India ranks 36 out of 180 countries on per capita waste generation; higher than its neighbors – Pakistan and China, ranking 40 and 55 respectively. Moreover, China has even seen a falling trajectory in per capita waste generation has been falling over the last decade, while India continues to rise.[37]

With all the transformation in the sector, most Indian cities still face the challenge of improper waste management. SWM is a critical service for ULBs since many public health issues relate to it. The situation is particularly bad in the unauthorized settlements and slums in urban areas where municipal solid waste management is virtually absent. Inadequate waste disposal may cause severe environmental and health problems. Updates to the SWM framework in 2026—seek to strengthen accountability for ULBs, improve segregation and processing infrastructure, and reduce dependence on dumpsites and unscientific landfills.

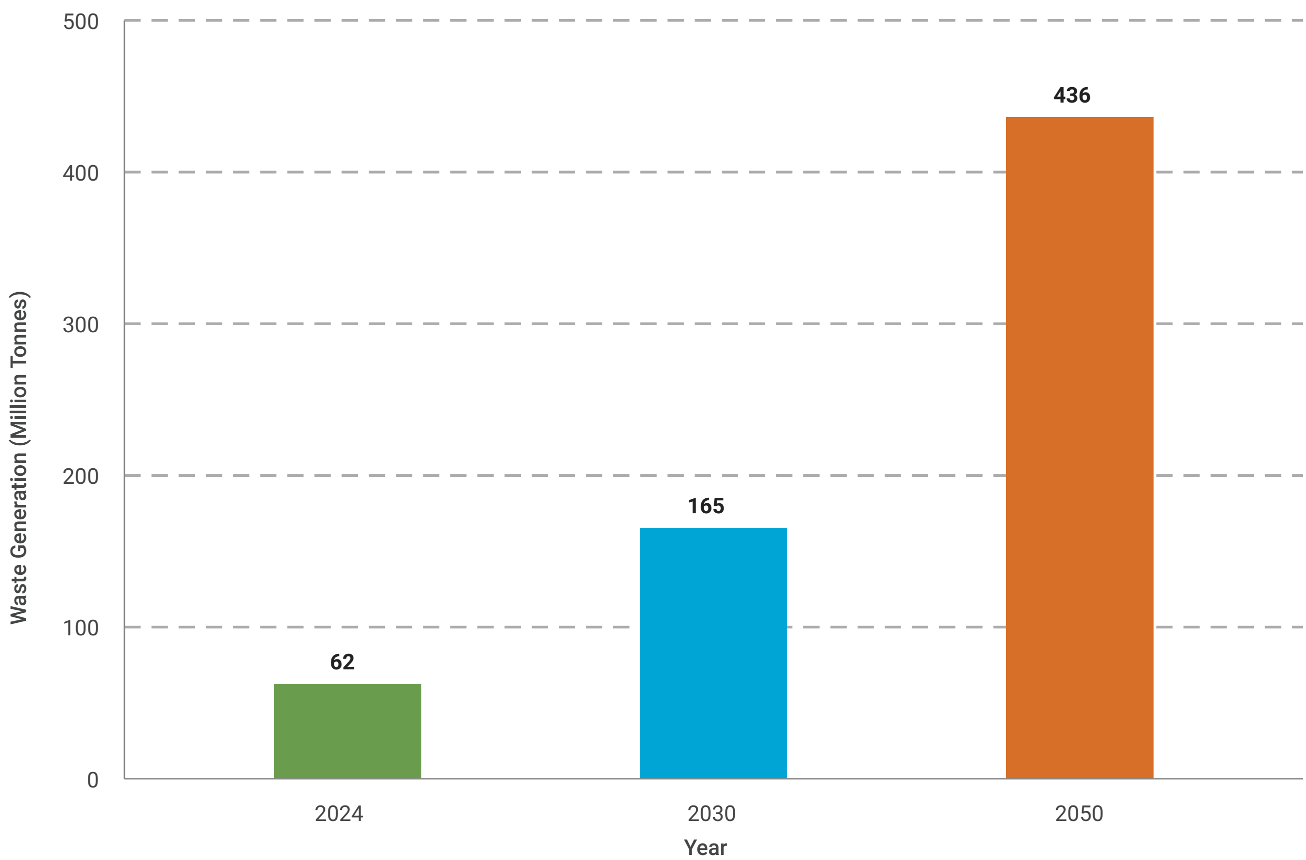


Fig 9. Projected waste generation in India to 2050 (Source: NITI Aayog)
Source: NITI Aayog

India currently generates over 1,70,000 tonnes of MSW every day which is equivalent to over **70 daily fillings** of the Ghazipur Landfill. India is the seventh-largest solid waste generator globally and third among G20 nations.

We generate over 62 million tons of waste annually[38] and will generate 165 million tonnes of waste by 2030 and 436 million tonnes by 2050.[39]

This dramatic increase is largely driven by India's rapid population growth and rising incomes, which eventually leads to increased consumption.

The country's official waste generation rate is approximately 0.12 kilograms per capita per day, which is likely underestimated.[40] As a response to this growing problem, the solid waste management sector in India has witnessed significant growth in recent years due to the government's push towards cleanliness and sanitation, facilitated by initiatives such as the SBM. The market for solid waste management in India is expected to grow at a compound annual growth rate (CAGR) of 7.5% during the forecast period (2021-2026)[41], driven by factors such as increasing urbanization, rising awareness of waste management, and growing investments in waste management infrastructure.

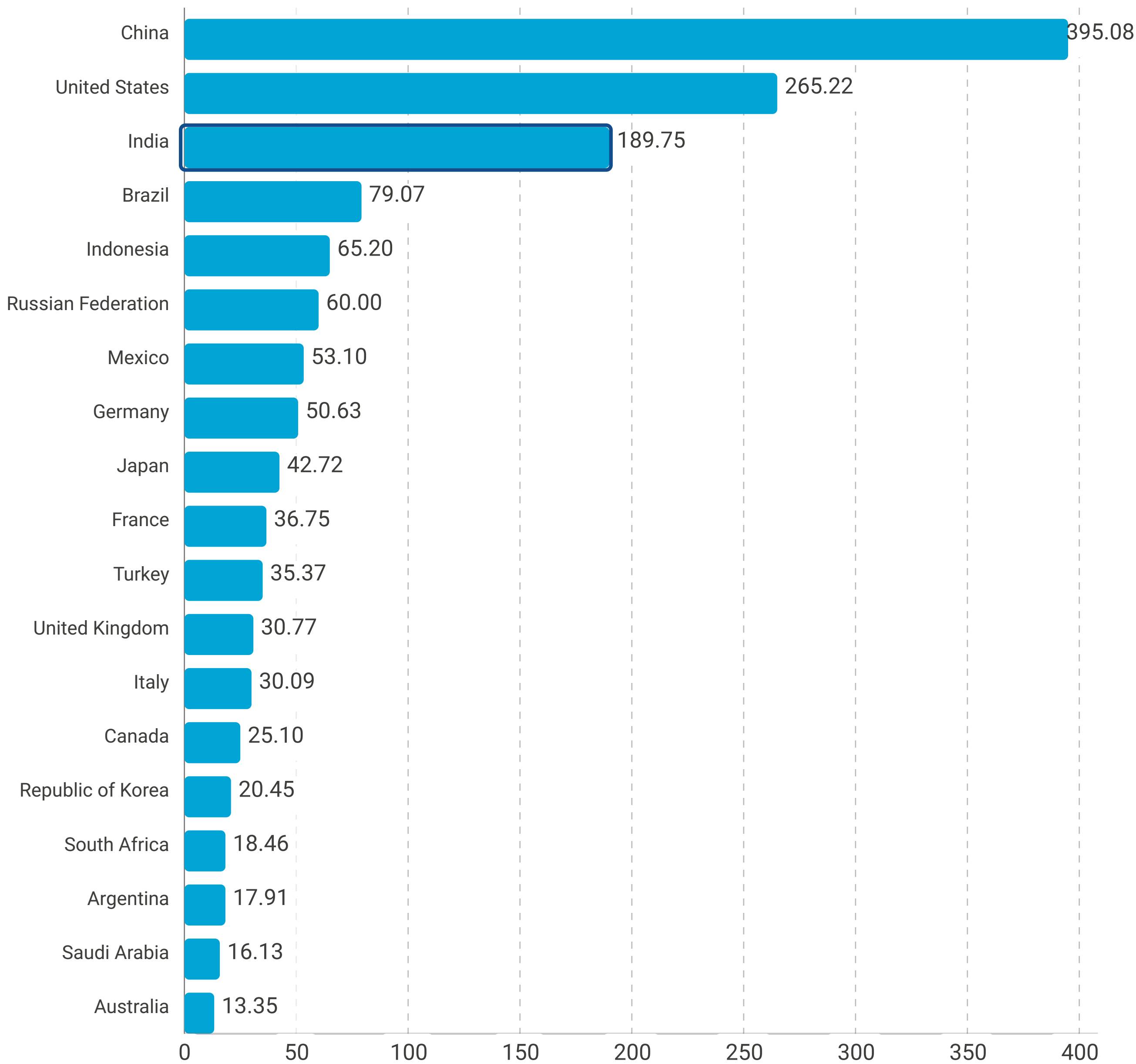


Fig 10. Municipal solid waste generated among G20 countries, MT/yr

Source: NITI Aayog

1.3 Governance and Institutional Framework for Municipal Solid Waste Management in India

SWM in India is a multi-layered responsibility, meticulously structured across central, state, and local governmental bodies. This comprehensive system is firmly rooted in constitutional provisions and detailed legislative frameworks.

1.3.1 Legal and Constitutional Basis

The Constitution of India places public health and sanitation in the State List, making State Governments primarily responsible for solid waste management. The 74th Constitutional Amendment Act, 1992, further empowered Urban Local Bodies to manage functions such as sanitation and waste within their jurisdictions. At the national level, the Environment (Protection) Act, 1986 provides the legal basis for rules and standards. The SWM Rules, 2016 operationalise[42] this framework by clearly defining the roles of Central ministries, State authorities, and municipalities. Subsequent updates to the regulatory framework, including revisions introduced in 2026, have further strengthened provisions related to source segregation, waste processing infrastructure, monitoring mechanisms, and landfill management.

1.3.2 Key Stakeholders and Their Detailed Responsibilities

At the Central Level

The Central Government assumes the pivotal role as the **regulatory authority** for SWM. It is responsible for creating overarching regulation, policies, and acts, including the comprehensive **SWM Rules, 2016** and subsequent updates to the regulatory framework introduced in 2026. Beyond its legislative function, the Central Government is also tasked with developing and overseeing **national strategies** for waste management. Crucially, it provides significant **financial support** to states through various schemes, most notably the **SBM**, to facilitate the implementation of SWM initiatives.

- **Ministry of Environment, Forest and Climate Change (MoEFCC)**

  MoEFCC is responsible for **formulating comprehensive policy guidelines** and providing essential **technical assistance** to states and cities to improve their SWM practices. Beyond policy, it supports **human resource development** in the SWM sector and acts as a crucial intermediary for mobilizing **external funding** for SWM projects. The MoEFCC also oversees the overall monitoring and implementation of SWM rules, with a dedicated **Central Monitoring Committee (CMC),** chaired by its Secretary, responsible for this oversight, with its mandate renewed every three years.

- **Ministry of Housing and Urban Affairs (MoHUA)**

  MoHUA is specifically entrusted with providing **technical guidelines and financial support** for SWM. A significant contribution in this regard is the publication of the **Municipal Solid Waste Management Manual, 2016,** which meticulously aligns with the SWM Rules, 2016, and its revision, offering a structured and practical approach to waste management practices. Since the launch of SBM, MoHUA's purview has expanded to emphasize **waste segregation at source,** promoting **advanced waste treatment methods,** and ensuring the **scientific disposal of waste** across urban centers. MoHUA coordinates with state governments and Union Territory administrations to periodically review measures, formulate policies (e.g., National SWM Policy, National Urban Sanitation Policy), and facilitate regional-level strategies. It also promotes **research and development in SWM,** disseminates information, and provides **technical guidance and project financing support** to states and ULBs.

Central Pollution Control Board (CPCB)

Operating under the administrative control of the MoEFCC, as per the provisions of the **Environment (Protection) Act, 1986,** the CPCB provides vital **technical services to the Ministry.** It plays a crucial role in coordinating the activities of the **State Pollution Control Boards (SPCBs)** by offering comprehensive technical assistance and guidance on various aspects of waste management, including the proper handling of sanitary waste and the scientific disposal of legacy waste. The CPCB also serves as an important body for resolving disputes amongst SPCBs. Furthermore, the CPCB plays a pivotal role in **standard setting, review, monitoring, reporting, and coordination** for the effective implementation of MSW management under the SWM Rules.

At the State Level:

State Governments bear the significant responsibility of **implementing national SWM policies and regulatory frameworks** within their respective jurisdictions. They function as the essential **coordinating authority** between the Centre and the ULBs, ensuring strict compliance with all SWM regulations. Beyond coordination, state governments are responsible for **allocating necessary resources,** diligently **monitoring progress,** building institutional capacity, and providing both **technical and financial support** to ULBs for the effective on-ground implementation of SWM initiatives, including those directly under centrally sponsored schemes such as the SBM.

State Pollution Control Boards (SPCBs)

SPCBs are the principal agencies responsible for the **administration and enforcement of acts and rules pertaining to environmental protection** within their respective states. They are specifically tasked with **monitoring and implementing the provisions of the MSW Rules,** which includes ensuring[43] compliance with prescribed standards regarding groundwater, ambient air quality, compost quality, and incineration standards. SPCBs also collect crucial data from municipalities and submit consolidated reports to the CPCB, enabling effective tracking of progress and robust enforcement of regulations.

State Urban Development Departments (UDDs)

UDDs are responsible for meticulously **preparing the state's SWM policy and strategy** in close consultation with a wide range of stakeholders, including informal sector waste pickers, self-help groups, and other community organizations. They play a key role in approving **land transfers from the state to ULBs for SWM projects** and significantly contribute to **capacity building** through organized training programs. By providing strategic oversight, UDDs ensure that municipal authorities are equipped with the necessary resources to implement effective waste management solutions.

- **Urban Local Bodies (ULBs) / Panchayats**

  City Municipal Corporations and **City or Town Municipal Councils** (and **Panchayats** in rural areas) are the front-line entities tasked with implementing the SWM Rules, 2016, subsequent regulatory updates, including those introduced in 2026[44], at the city and town levels. Their responsibilities encompass the entire waste management chain, including overseeing waste collection, segregation at source, treatment, and final disposal. ULBs are also authorized to issue permits and contracts to private sector entities for specific waste management services. In addition to outsourcing, ULBs also provide crucial in-house services to ensure efficient waste handling and sanitation across their urban and rural areas.

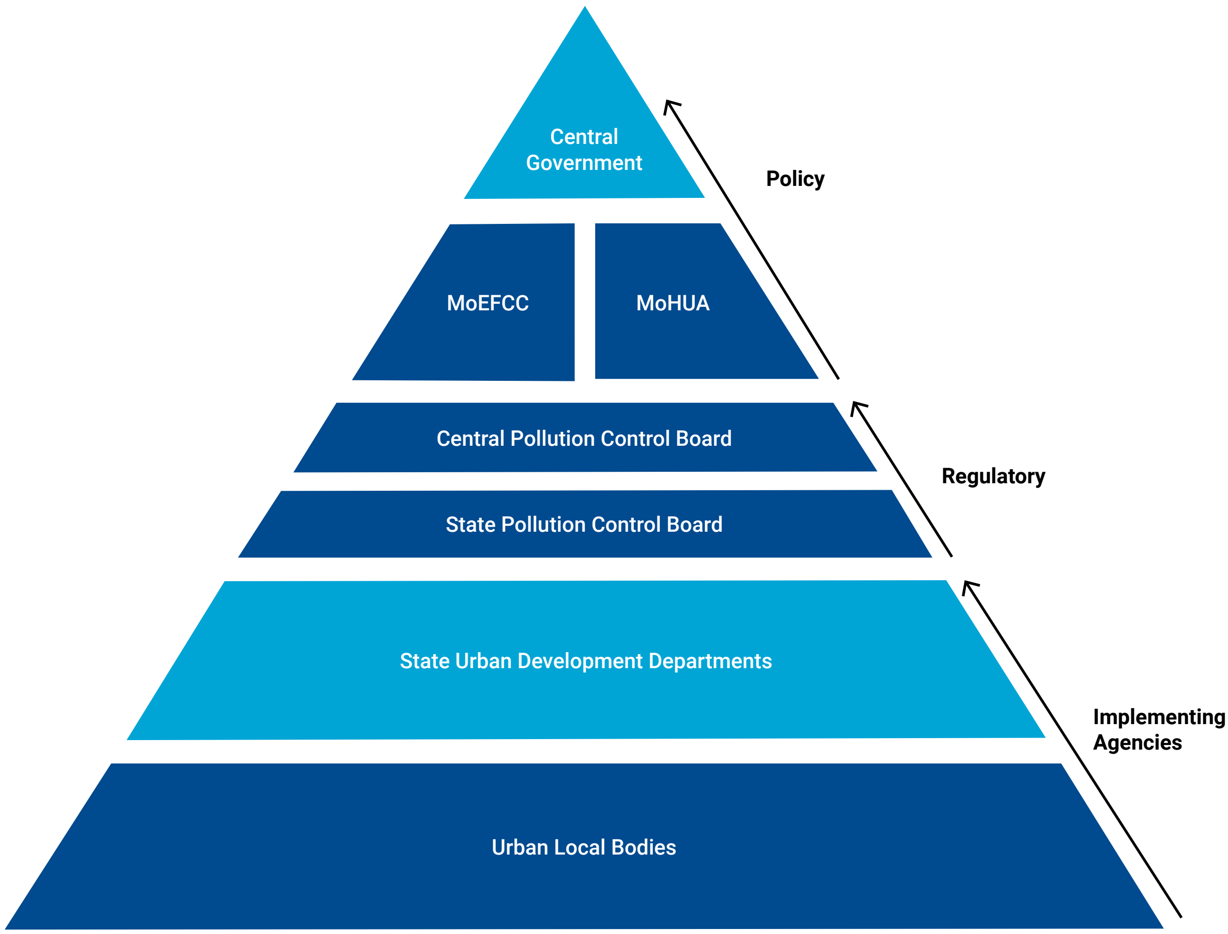


Figure 11: Institutional structure of municipal solid waste management in India

1.3.3 National and International Commitments

1.3.3.1 National Commitments

Over the past decade, the government of India, in collaboration with state governments and union territories (UTs), has initiated projects such as the Waste to Wealth Mission (2020) and the development of 100 smart cities across the country (2015).[45]

SBM, 2014: With mere 18% waste treatment capacity in 2014, India's waste management efficiency was extremely critical and posed huge challenges towards the environment. Following just a few years of the implementation of the SBM, **India achieved marked progress: it now has 70% waste treatment capacity as per 2021 records.**[46] Launched on October 2, 2014, the SBM comprises two main components: SBM (Urban) under the Ministry of Housing and Urban Affairs and SBM (Rural) under the Ministry of Drinking Water and Sanitation, now part of the

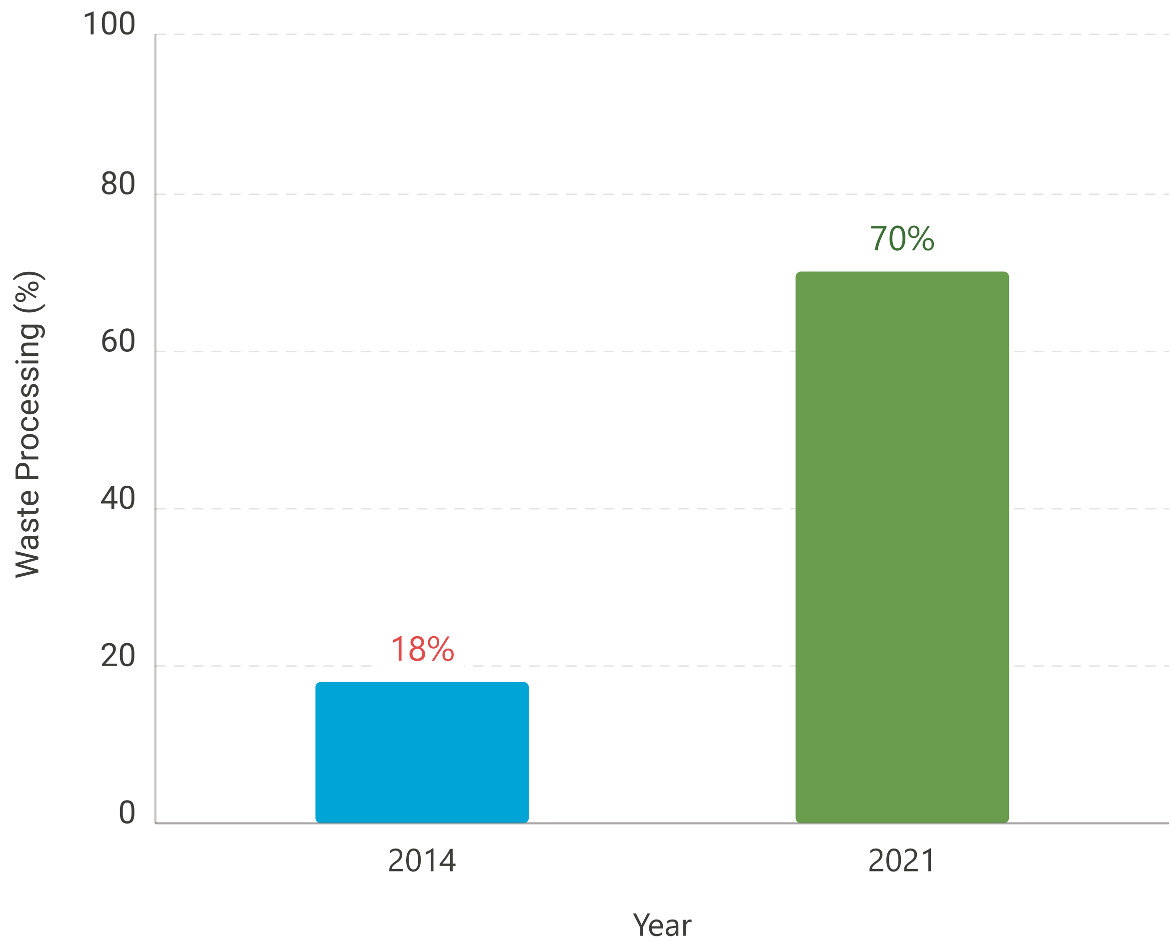


Figure 12: India's waste processing progress, 2014 and 2021 (Source: CPCB)
Source: Waste Wise Cities, NITI Aayog

Ministry of Jal Shakti. SBM aims to eliminate open defecation and achieve comprehensive solid waste management across all urban and rural areas in India. The urban component (SBM-U) focuses on ULBs and includes initiatives such as capacity building, construction of household, community, and public toilets, information, education and communication (IEC) activities, public awareness campaigns, and solid waste management, including fecal sludge management. SBM-U has adopted a multipronged approach to address persistent challenges in SWM by fostering motivation, providing financial support, and instilling a sense of accountability among ULB personnel, alongside large-scale citizen awareness campaigns.

MSWM Rules 2000 and SWM Rules 2016 and Revised MSW Rules, 2026[47]

MoEFCC, GoI, promulgated the first comprehensive Municipal Solid Waste Management (MSWM) Rules in 2000. These rules delineated detailed mandates for municipal solid waste management and designated the CPCB and SPCBs as the primary agencies responsible for monitoring implementation in union territories and states, respectively.

With the three basic principles of circular economy (i.e., reduce, reuse, and recycle) in mind, the MoEFCC also amended India's SWM rules in 2016. These initiatives, combined with stricter enforcement of the updated SWM rules by the CPCB, encourage every ULB in India to develop integrated waste management systems, wet and dry segregation, source-specific collection, home composting/ biomethanation, and material and energy recovery from waste.

The revised rules transferred the responsibility for solid waste management in urban areas to the UDDs and ULBs of each state. All municipal corporations and municipalities are now required to develop a comprehensive Solid Waste Management Plan. To facilitate the operationalization of the SWM Rules 2016, MoHUA, through the Central Public Health and Environmental Engineering Organization (CPHEEO), published technical manuals in October 2016, specifying the standards and actions necessary for ULBs to implement these rules effectively.

Key Features of the Solid Waste Management Rules, 2016 (with subsequent regulatory strengthening in 2026) – relevant for landfill management

- **01** Mandatory four-stream segregation at source (wet, dry, sanitary, and special-care waste);
- **02** An Extended Bulk Waste Generator Responsibility (EBWGR) framework for large generators;
- **03** A centralised digital monitoring portal replacing multi-step physical reporting;
- **04** A phased RDF substitution mandate for cement and waste-to-energy industries, rising from 6% at implementation to 15% within six years;
- **05** Strengthened landfill restrictions, confining landfilling to non-recyclable, non-recoverable, and inert waste;
- **06** Environmental compensation on polluter-pays principles; and
- **07** Time-bound legacy dumpsite remediation.[48]

1.3.3.2 International Climate Commitments and their linkage to Waste Management

India's international climate commitments are deeply intertwined with its waste management strategies, primarily because the waste sector is a significant, and rapidly growing, contributor to the country's GHG emissions. To meet its global pledges, India must actively address waste generation and disposal.

1. Waste as a Key GHG Emitter in India's Climate Reports

Fourth Biennial Update Report (BUR-4) to the UNFCCC:

India's official reporting to the United Nations Framework Convention on Climate Change (UNFCCC) explicitly identifies the waste sector as the **fourth-largest contributor to overall GHG emissions** in the country.

The BUR-4 highlights an alarming **226% growth in emissions from the waste sector between 1994 and 2020.** A substantial portion of these emissions come from methane (CH_4), a potent GHG released during the anaerobic decomposition of organic MSW in unscientific landfills. In 2020 alone, 912 Gg of methane were produced from MSW at landfills. Open waste burning also contributes to CO_2 emissions.

First Biennial Transparency Report (BTR-1) to the UNFCCC: India has transitioned from Biennial Update Reports (BURs) to Biennial Transparency Reports (BTRs) under the Paris Agreement's Enhanced Transparency Framework. The BTR-1 continues to recognize the waste sector as an important source of GHG emissions, reinforcing the need for improved waste management, methane mitigation, and circular economy approaches to support India's climate targets.

2. Integration into India's Nationally Determined Contributions (NDCs)

India's updated Nationally Determined Contribution (NDC 3.0) under the Paris Agreement commits to reducing the emissions intensity of its GDP by 47% by 2035 (from 2005 levels), achieving 60% cumulative installed electricity capacity from non-fossil fuel-based energy resources by 2035, and supporting its long-term goal of net-zero emissions by 2070. Effective solid waste management is a key enabler of these climate commitments by reducing landfill methane emissions, enhancing resource recovery, and advancing the circular economy. The 2026 revisions to India's solid waste management regulatory framework further support these goals by strengthening source segregation, improving waste processing, and accelerating the remediation of legacy dumpsites.

Table 8: India's NDC targets and the Waste Sector's Contribution

International Commitment	Role of Waste Sector	How to achieve progress in Waste Sector
Reduce emissions intensity of GDP by 47% by 2035	Implement sustainable waste management practices to reduce emissions	SWM and other policies like SBM promote more sustainable methods of waste management and will directly lead to lower emissions
Achieve 60% non-fossil fuel-based power capacity by 2035	Contribute through waste-to-energy projects	Increase number of operational waste-to-energy plants and landfill gas capture to use waste as a source of energy generation
Create additional carbon sink of 3.5 to 4 billion tonnes CO_2 equivalent by 2035	Indirectly support through reduced landfill emissions	Converting organic waste into biochar acts as a carbon sequestration activity

Apart from these targets, India's remaining goals for better waste management also have clear linkages with international climate commitments.

Table 9: Linking Waste Management Goals with International Climate Commitments

Category	Description	Linkage with Climate Commitments
Waste Reduction	Implement strategies to minimize waste generation at the source.	Lower emissions from waste disposal.
Recycling and Composting	Enhance recycling rates and promote composting to divert organic waste from landfills.	Reduce methane emissions and divert waste from landfills.
Waste-to-Energy Initiatives	Convert municipal solid waste into energy via incineration or anaerobic digestion.	Provide renewable energy and reduce reliance on fossil fuels.
Biogas Production	Utilize organic waste for biogas production.	Generate energy and reduce GHG emissions from landfills.
Landfill Management	Implement effective landfill management practices.	Mitigate methane release, minimize leachate production, and promote soil health.
Methane Capture	Use methane capture systems in landfills.	Significantly reduced methane emissions into the atmosphere.
Sustainable Landfill Practices	Adopt environmentally sound practices in landfill operations.	Minimize leachate production and promote soil health.

Multiple international agreements and conventions have been formed over the years to further the agendas of achieving climate and waste management goals. India has been a prominent member of these, further reaffirming the nation's commitment to local, regional, and global sustainable development.

Table 10: India's Affiliation to Multilateral Climate and Environmental Agreements

Multilateral Agreement	Description
Climate & Clean Air Coalition (CCAC)	India collaborates with the Climate and Clean Air Coalition (CCAC) to reduce short-lived climate pollutants (SLCPs) like methane and black carbon from municipal solid waste, partnering with organizations like TERI and local centers to build action plans for cleaner cities.
Basel Convention	Regulates the transboundary movement of hazardous wastes and their disposal to protect human health and the environment.
Stockholm Convention	Aims to eliminate or restrict the production and use of persistent organic pollutants (POPs).
Rotterdam Convention	Promotes shared responsibility and cooperative efforts among parties in the international trade of certain hazardous chemicals and pesticides.
Montreal Protocol	Aims to protect the ozone layer by phasing out the production and consumption of ozone-depleting substances.
Paris Agreement	An international treaty on climate change that aims to limit global warming and reduce GHG emissions.
Vienna Convention	The Vienna Convention is a framework treaty that aims to protect the ozone layer by promoting international cooperation and research.
South Asia Co-operative Environment Programme (SACEP)	To promote regional co-operation in South Asia in the field of environment, both natural and human in the context of sustainable development and on issues of economic and social development which also impinge on the environment and vice versa; to support conservation and management of natural resources of the region and to work closely with all national, regional, and international institutions, governmental and non-governmental, as well as experts and groups engaged in such co-operation and conservation efforts.

While India has not signed the Global Methane Pledge, it continues to address short-lived climate pollutants like methane holistically, through broader GHG reduction efforts under its NDCs, and waste-sector interventions targeting landfill and organic waste emissions.

Furthermore, specific to plastic waste management, deliberations attempting to formulate a Global Plastics Treaty through cooperation amongst 175 member states and inputs from various other relevant stakeholders, have been going on through *intergovernmental negotiating committees (INCs).* India at INC-5, held in Busan November 2024, called for balance between plastic pollution control and developing economies' growth. In its position, India advocates for nationally driven policies noting the vital role of plastics in advancement of developing countries and hence an opposition to a global plastics phase out. The nation's stand is in tandem with "like-minded" parties like China and Saudi Arabia. However, this stance has also received criticism, stating that it shows fossil fuel dependency, and a Global Treaty founded on such a perspective would eventually create such an open-ended and diluted mechanism that it would have a negligible impact on the entire lifecycle of plastics.

Table 11: Linkages between Solid Waste Management and the Sustainable Development Goals[49]

SDG Goal & Target	Description of SDG Target	SWM Contribution/Linkage
SDG 3: Good Health and Well-being	3.9: Substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	Proper SWM reduces disease vectors, prevents contamination of water and soil, and improves air quality.
SDG 6: Clean Water and Sanitation	6.3: Improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials	Effective SWM prevents leachate and waste runoff into water bodies, improving water quality and sanitation.
SDG 8: Decent Work and Economic Growth	8.5: Achieve full and productive employment and decent work for all women and men	SWM sector creates jobs in collection, segregation, recycling, and processing, supporting livelihoods.
SDG 11: Sustainable Cities and Communities	11.6: Reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	SWM is critical for reducing urban pollution, improving urban living conditions, and making cities more sustainable.
SDG 12: Responsible Consumption and Production	12.4: Achieve environmentally sound management of chemicals and all wastes throughout their life cycle	SWM encourages recycling, resource recovery, and safe disposal, promoting a circular economy.
SDG 13: Climate Action	13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters	Improved SWM reduces GHG emissions from landfills and open burning, contributing to climate action.

[Sources: Ministry of Environment, Forest & Climate Change, Government of India, UN Sustainable Development Goals Knowledge Platform, Annual Report 2020-21 on Implementation of Solid Waste Management Rules, CPCB, EnviStats India 2022, MoSPI]

Therefore, effective waste management is integral to addressing environmental challenges and advancing sustainability objectives. It involves the systematic collection, transportation, treatment, and disposal of waste in a manner that safeguards public health and the environment. Proper waste management mitigates pollution, conserves natural resources through recycling and resource recovery, and contributes to economic development by generating employment opportunities. According to the MoEFCC, robust waste management practices are aligned with several SDGs, promoting environmental cleanliness, social equity, and economic growth. By fostering a circular economy—where waste generation is minimized, and resources are reused—effective waste management ensures a sustainable future for succeeding generations.

1.4 Understanding the Municipal Solid Waste Value Chain:

We now **focus on the formal SWM value chain** as it operates in India's urban environments. This system, characterized by its emphasis on infrastructure, technology, and a structured process from collection to resource recovery, is a direct response to the high volume and complex nature of waste generated in ever-expanding cities. This approach is distinct from the more informal, decentralized methods prevalent in rural India. In smaller towns and rural settlements, decentralized waste management—particularly household and community composting of biodegradable waste—is recommended to reduce the quantity of waste requiring transportation and disposal, while centralized treatment facilities are reserved for waste streams requiring economies of scale. This fundamental difference is officially acknowledged and guided by government initiatives, such as the **SBM (Grameen) Phase II Operational Guidelines** by the Ministry of Jal Shakti, which outlines a separate, more localized strategy for managing waste tailored to the unique composition and infrastructure of villages.

The SWM value chain in urban India currently follows the course of **collection, segregation transportation, treatment, disposal, and processing.**[50] Collection and transportation handle the largest volumes, which are then segregated and directed to treatment, disposal, and processing. These final stages are expected to see significant growth, driven by a rising focus on **sustainable waste management** and accompanying **technological advancements.**

The flowchart below describes the various stages involved in the life cycle of waste management in India. Depending on the category and composition of waste, it is segregated and sent to different processing facilities to recover the waste as a resource to minimize the amount of waste reaching landfills.

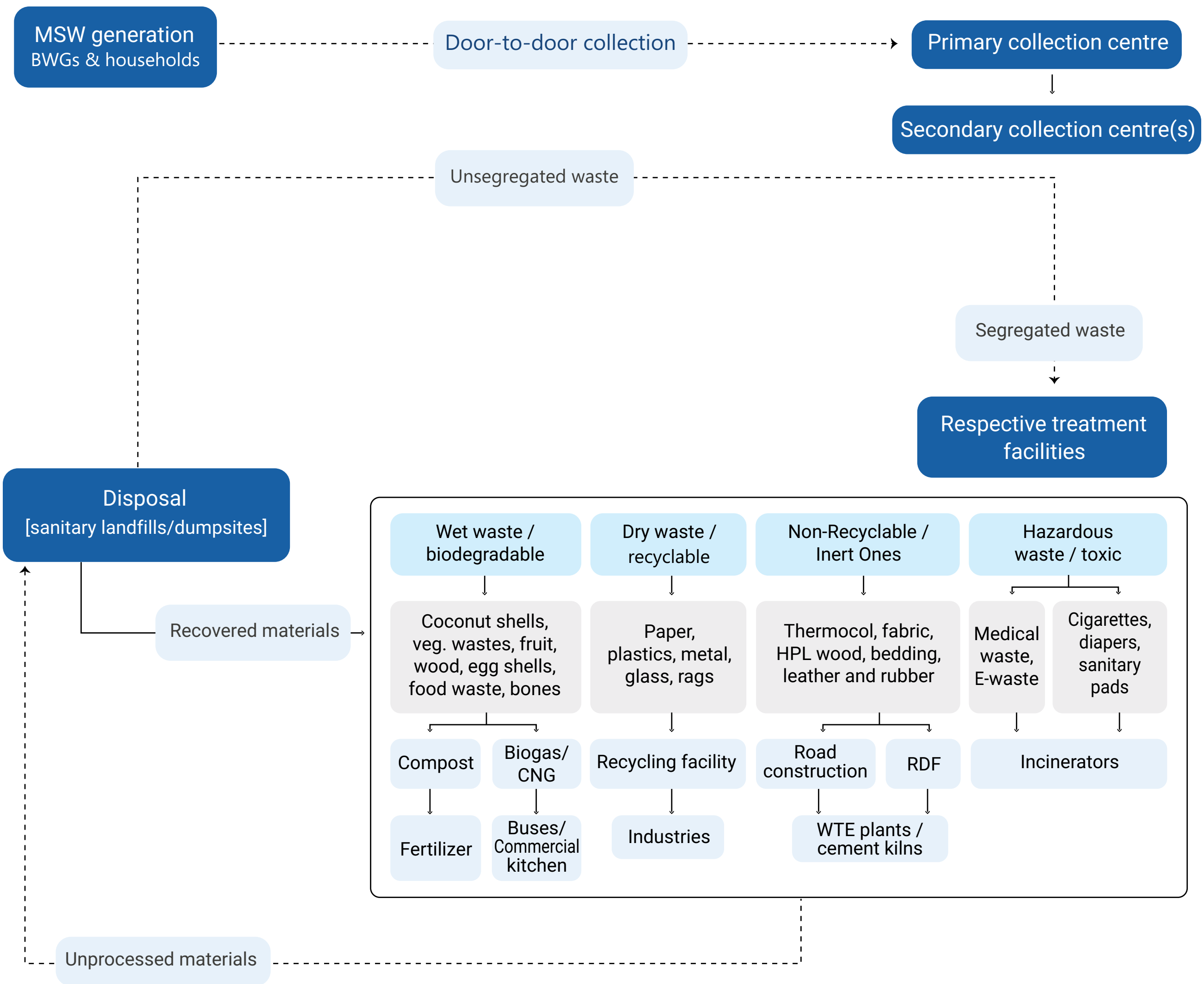


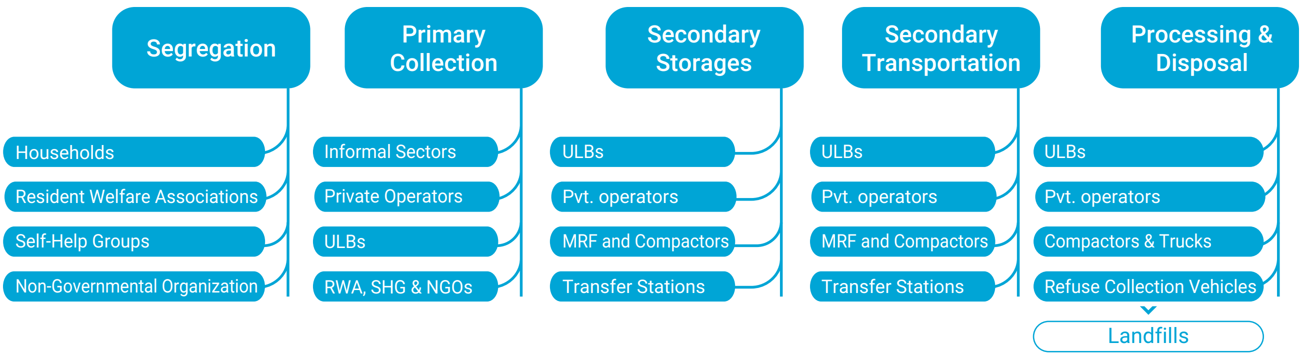
Figure 13: Current municipal solid waste management system in India from generation to disposal

1.4.1 Operational Framework of Solid Waste Management

The SWM process in India is governed by the SWM Rules, 2026 that regulate source segregation into biodegradable, non-biodegradable, and special care and sanitary waste; formalisation of collection workers; transportation to processing sites; appropriate treatment via composting, biomethanation, waste-to-energy plants, or other methods; and ultimately, scientific disposal.

In India, each of the stages of waste management **– collection, segregation, transportation, and processing –** are part of both centralized and decentralized systems, but **how** they are carried out and the **emphasis** placed on each stage differ significantly.

The SWM system is designed with the objective that minimum amount of waste should reach landfills, and there is maximising of resource recovery, considering local needs and conditions, and integrating suitable processes and technologies. Various stakeholders ranging from an individual waste generator to government and private institutions are part of SWM, from segregation to final disposal. The details regarding challenges and technical aspects of the operational stages in SWM are outlined in sections below the figure.



1.4.2 Waste Segregation at Source

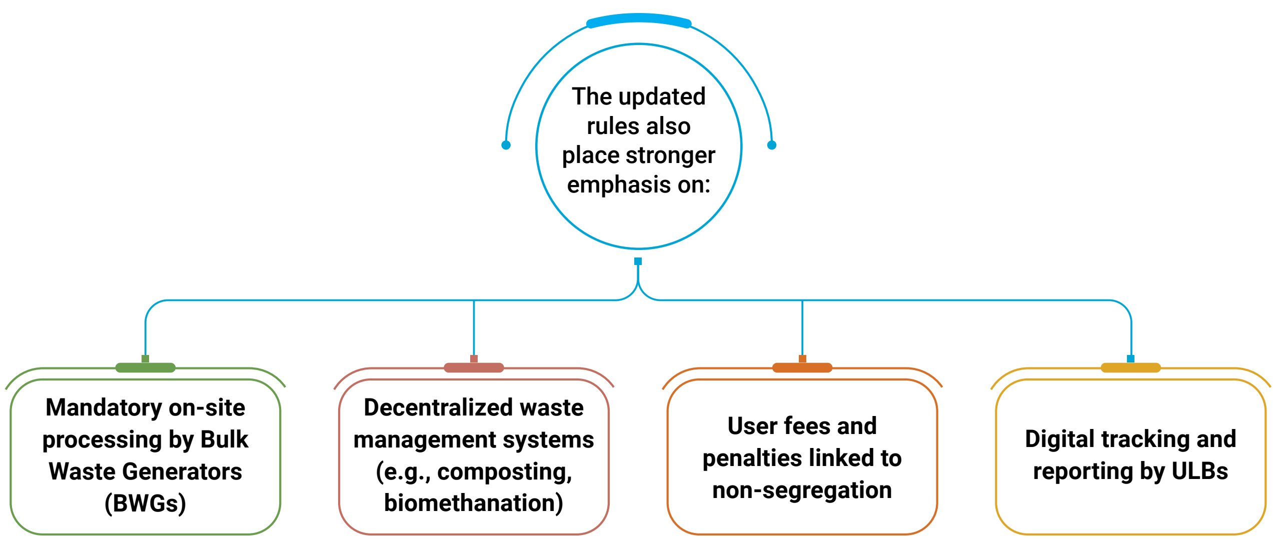
Waste segregation involves the systematic separation of waste at the point of generation, transforming it from a liability into a valuable resource by preserving its utility for subsequent reuse, recycling, and recovery processes.

The imperative of source segregation has been further strengthened under the SWM Rules, 2026, which build upon and expand the provisions of the earlier Solid Waste Management Rules 2016.[51] The updated framework places greater enforcement emphasis, accountability mechanisms, and monitoring requirements on waste generators and ULBs.

Under SWM 2026, all waste generators—including households, institutions, and commercial establishments—are required to ensure segregation at source into multiple defined streams, with stricter compliance expectations and penalties for non-adherence. The framework also encourages further sub-segregation of dry waste into recyclable categories to enhance material recovery and circularity.

Table 12: Primary Categories of Waste Segregation and Prescribed Handling Methods

Waste Stream	Description	Processing / Handling Method
Wet Waste	Includes kitchen waste, vegetables, fruit peels, meat, flowers, etc.	To be composted or processed through biomethanation at the nearest facility
Dry Waste	Comprises plastic, paper, metal, glass, wood, rubber, etc.	To be transported to Material Recovery Facilities (MRFs) for sorting and recycling
Sanitary Waste	Includes used diapers, sanitary towels, tampons, condoms, etc.	To be securely wrapped and stored separately for safe collection and disposal
Special Care Waste	Includes paint cans, bulbs, mercury thermometers, medicines, etc.	To be collected by authorised agencies or deposited at designated collection centres



Ideally, waste segregation should commence at the point of origin—residential, commercial, or institutional. This approach recognizes that effective waste management strategies must be tailored to local demographic and socio-economic contexts. Source segregation is critical for enabling decentralized solutions, improving collection efficiency, and maximizing recovery of valuable resources.

Despite policy advancements, segregation at source remains uneven across India. While select States/UTs have reported near 100% compliance, many urban local bodies continue to face challenges due to behavioral gaps, inadequate infrastructure, and weak enforcement, resulting in inefficiencies across the waste management chain.

Consequences of non-segregation

- Failure to implement effective waste segregation at the source leads to a cascade of detrimental environmental and economic consequences. The commingling of organic waste with other streams results in anaerobic decomposition, generating significant quantities of methane (CH_4). Moreover, the contamination of recyclable materials drastically diminishes their marketability and economic value, thereby impeding resource recovery efforts and exacerbating the overall waste management challenge.

Case Study: Panaji, Goa – A Coastal City's Commitment to Segregation

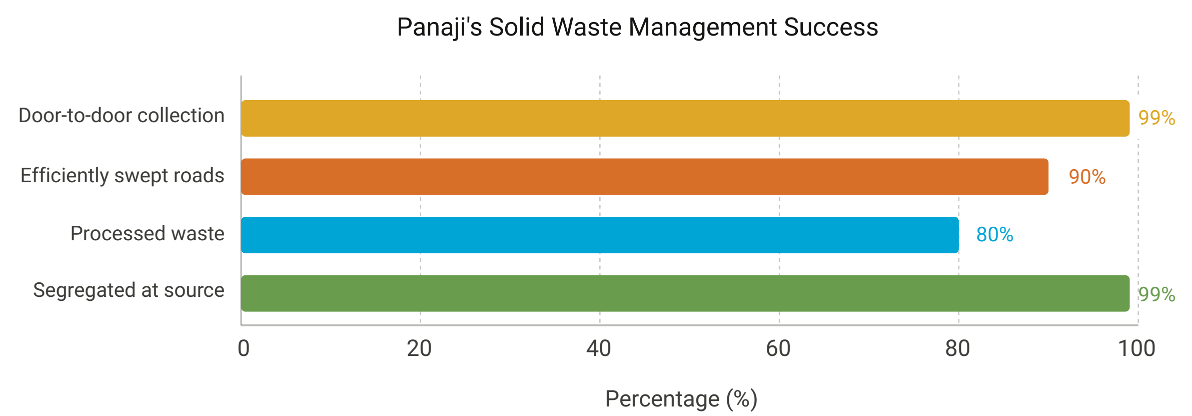


Figure 14: Solid waste management performance indicators, Panaji, Goa

Panaji, Goa, has emerged as a shining example of effective solid waste management, demonstrating a long-term commitment to segregation, sorting, and recycling. The city's Corporation (CCP) has consistently worked for over 15 years to improve methods and actively engage citizens in its endeavors. Today, an impressive 99% of the waste collected is segregated at the source, using either a four-way or two-way system. This dedication to segregation allows the city to process 80% of its waste, maintain efficiently swept roads (90%), and provide door-to-door collection to 99% of stand-alone houses. Aerobic composting, utilizing masonry units and crate systems at decentralized facilities, contributes to an existing processing capacity of 20 TPD. Only 23 TPD of waste is sent to landfills, comprised of street sweeping (5 tonnes), construction debris (10 tonnes), and horticultural waste such as tree branches (8 tonnes). Notably, the city currently operates without a sanitary landfill, relying instead on temporary waste sites identified on an as-needed basis.

Source: Waste Wise Cities, NITI Aayog

1.4.3 Waste Collection and Transportation

Following successful segregation at source, the MSWM value chain encompasses collection and transportation, which together constitute the largest share of expenditure for ULBs. The efficiency of this stage is strongly influenced by the type, volume, and characteristics of waste generated.

Under the SWM Rules 2026, the collection and transportation system has been further strengthened from 2016. Now, every local body must arrange door-to-door collection using covered, compartmentalized vehicles to ensure that no intermixing occurs until the waste reaches its designated processing facility. Additionally, the rules mandate that cities with a population exceeding five lakhs must equip their collection fleets with GPS tracking devices to digitally monitor all waste management activities.

Collection Systems

Collection methodologies are broadly categorized into:

Primary Collection

Direct collection of segregated waste from the point of generation, including **households, commercial establishments, institutions, and BWGs.** This primarily involves **door-to-door collection systems,** which are now mandated to ensure **segregated waste pickup** under SWM 2026.

Secondary Collection

Collection of waste from **community bins, secondary storage points, or designated aggregation centers** for further transport to processing or disposal facilities. SWM 2026 places increased emphasis on **minimizing secondary storage points** to reduce waste accumulation and environmental leakage.

Transportation Systems

Waste transportation—defined as the movement of waste from collection points to processing or disposal sites—represents a **significant share of municipal budgets** and is critical to maintaining the integrity of segregated waste streams. It is categorized as:

Primary Transportation

Movement of waste from households or generation points to **local storage depots or transfer stations**

Secondary Transportation

Movement of waste from **transfer stations or storage facilities to centralized processing plants or sanitary landfills**

Under SWM 2026, transportation systems are required to:

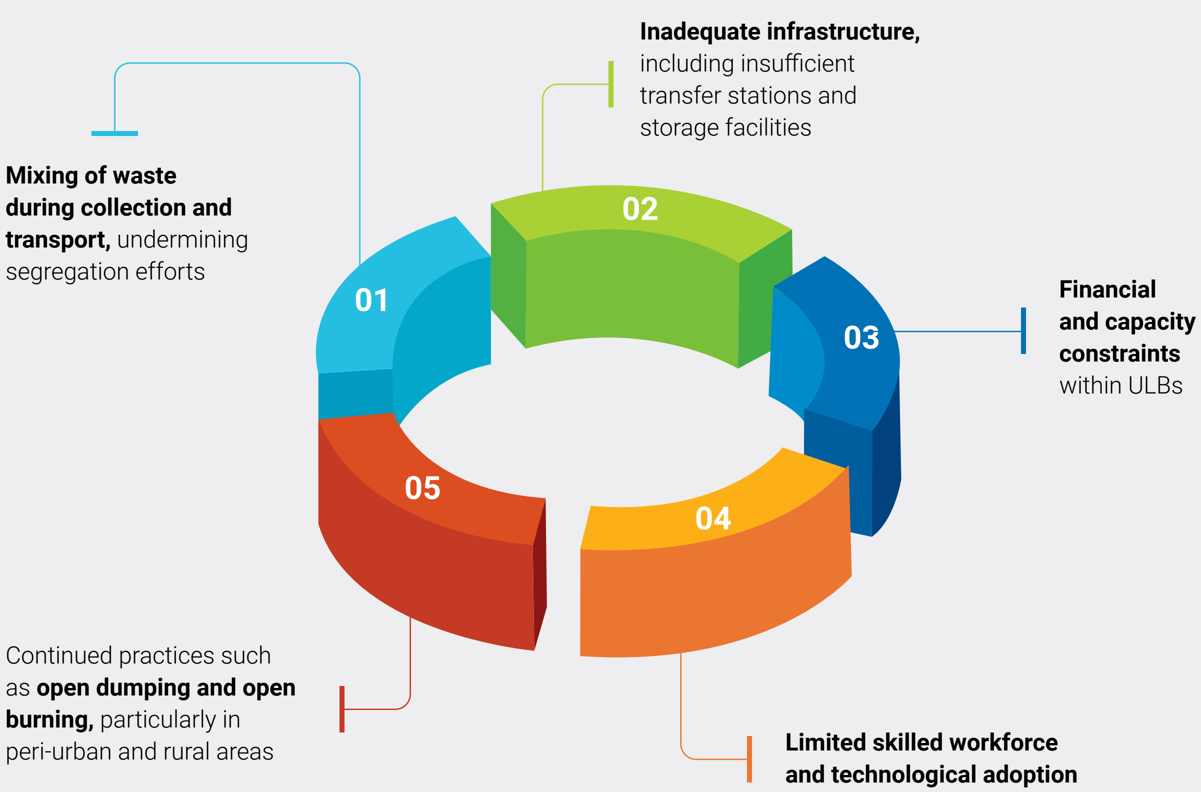
- Ensure **no mixing of segregated waste streams during transit**
- Use **covered and compartmentalized vehicles**
- Incorporate **GPS-based tracking and route optimization**
- Enable **traceability and data reporting** for improved governance

Door-to-door collection vehicles are increasingly equipped with **color-coded, segregated compartments,** reinforcing behavioral change and supporting compliance with source segregation norms. ULBs deploy a range of vehicles—including **compactor trucks, tractor-trailers, mini-tippers, auto-tippers, and non-motorized carts (particularly in rural areas)—**to ensure waste conveyance across diverse geographies.

System Performance and Challenges

India has achieved **high overall waste collection efficiency (>95%)**[52]**;** however, this metric often masks **gaps in segregation compliance and service quality.** The MSWM ecosystem continues to reflect a **hybrid system,** where formal municipal mechanisms co-exist with an extensive **informal sector,** including waste pickers and recyclers. SWM Rules 2026 and NAMASTE scheme explicitly encourage the **integration of informal workers into formal waste management systems** to enhance recovery efficiency and livelihoods.

Despite improvements, several challenges persist:



A key bottleneck remains the **uneven development of primary collection systems,** especially in smaller towns and rural regions. Inadequate coverage of **door-to-door collection services** and limited waste storage infrastructure contribute to inefficiencies and environmental risks. While SWM 2026 mandates **universal daily collection,** implementation often remains skewed toward **high-visibility areas such as main roads and markets,** with underserved areas receiving inconsistent service.

In addition, **street sweeping and public space waste management** continue to lack standardized benchmarks and monitoring systems in many jurisdictions, leading to irregular and suboptimal service delivery.

AN EXAMPLE OF HOW FEROZPUR EXCELLED IN DECENTRALISATION

Despite a legal mandate for **segregation at the source,** India's waste management system often operates with a significant gap where this crucial first step is skipped. While the **Solid Waste Management (SWM) Rules, 2016** and its 2026 revision require citizens to segregate their waste, a considerable amount of waste is still collected in a mixed, unsegregated form. This inefficiency is a major challenge acknowledged by government bodies, including in a 2018 report by the Comptroller and Auditor General (CAG). This practice forces informal workers to sort through mixed waste at transfer stations, contaminating recyclables and undermining the official goal of a circular economy.

Moreover, A 2024 report by the **Economic Advisory Council to the Prime Minister (EAC-PM),** for example, identifies the "absence of proper collection and segregation at the source" as a key challenge to effective waste management. This failure to implement source segregation compromises the entire value chain, as mixed waste contaminates valuable recyclables and complicates subsequent processing, ultimately hindering the country's move toward a circular economy.

1.4.4 Disposal and Treatment

As per the SWM Rules, 2016, sanitary landfilling[47] means the final and safe disposal of residual solid waste and inert wastes on land in a facility designed with protective measures against pollution of ground water, surface water and fugitive air dust, wind-blown litter, bad odour, fire hazard, animal menace, bird menace, pests or rodents, GHG emissions, persistent organic pollutants slope instability and erosion.

Building on the provisions of the **Solid Waste Management Rules 2016,** the **Solid Waste Management Rules 2026** further restrict landfilling to only **residual, non-recyclable, and inert waste,** while emphasizing **pre-treatment, landfill diversion, and scientific management and closure of existing dumpsites.** The updated framework introduces stronger requirements for **biomining and remediation of legacy waste, methane capture and landfill gas management, and improved monitoring and reporting mechanisms.** Despite these provisions, a significant proportion of waste in India continues to be disposed of in **unscientific dumpsites,** which remain outside formal accounting systems, creating critical data gaps. This not only undermines the effectiveness of waste management strategies but also contributes to **methane emissions, environmental contamination, and public health**

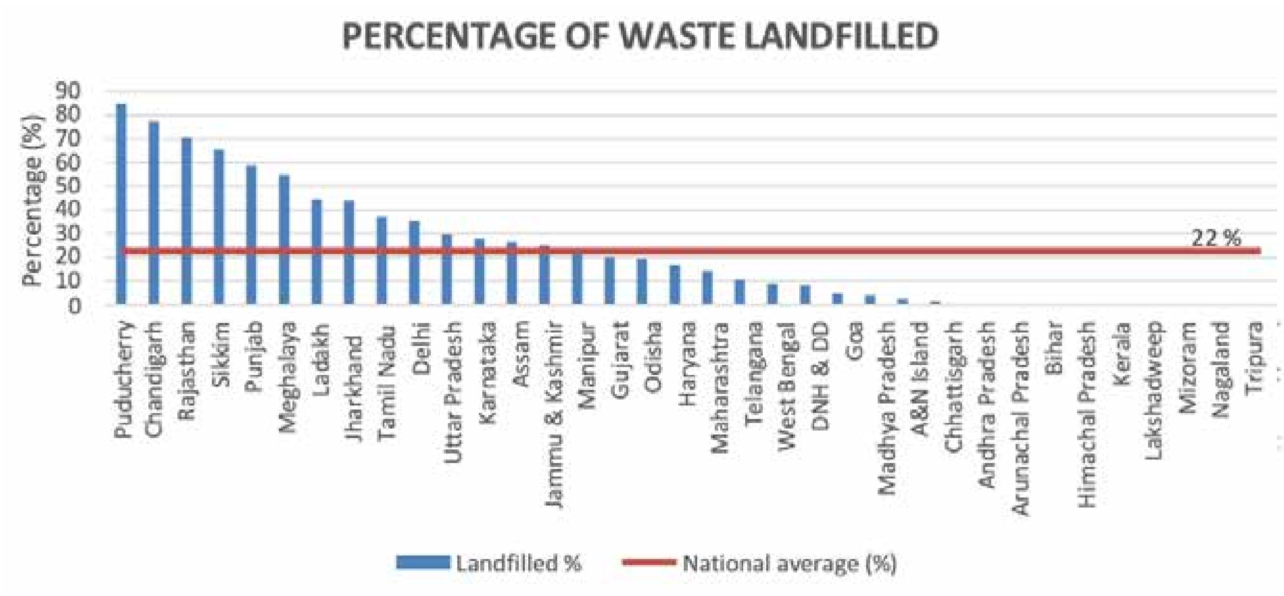


Figure 15: Share of waste landfilled across states and union territories in 2022-23
(Source: CPCB)

risks, highlighting the need for strengthened enforcement, infrastructure investment, and a transition toward decentralized and resource-efficient waste processing systems.

As per data from CPCB **(2022-2023)** a total of 38,147 TPD of waste disposed through sanitary landfill, which equates to **only 22% of the total waste generation** Reporting also notes **28,576 TPD (~16.7%)** identified as "Gap".

The disposal of waste through open dumpsite is not a recognised system for disposal of waste as per the Solid Waste Management Rules, 2026. Therefore, such disposal is not reflected either under processed/ treated, or under disposal through sanitary landfill. **The lack of data creates a significant authenticity gap, making it impossible to ascertain whether this portion of waste is being properly treated or is simply left to accumulate in unmanaged dumpsites.**

Despite India's evolving waste management policies, the continued practice of dumping untreated waste into landfills poses serious environmental and public health risks. These landfills, often poorly engineered and uncontained, become ticking time bombs—leaching toxic chemicals into the soil and groundwater, and releasing harmful gases like methane, a potent contributor to air pollution and climate change. The health toll is equally alarming: nearby communities and waste workers are exposed to infectious diseases, respiratory ailments, and long-term carcinogens. In cities like Mumbai and Delhi, where rapid urbanization collides with limited land availability, the pressure on existing landfill sites is immense. Overflowing dumpsites not only strain municipal logistics but also amplify the environmental footprint of urban living. The lack of adequate containment, treatment, and space makes waste management a critical urban crisis. To protect both people and the planet, there is an urgent need to move beyond policy on paper toward rigorous enforcement, investment in treatment infrastructure, and a transition to sustainable, decentralized waste practices.

India's waste management policy is driven by comprehensive rules aiming for scientific management and resource recovery. Key among them is the **Solid Waste Management Rules, 2026,** mandating **source segregation** (wet, dry,sanitary and special care) post its 2016 predecssor which already promoted **Waste-to-Energy** over landfilling for combustible waste. The **Plastic Waste Management Rules, 2016,** and **E-Waste (Management) Rules, 2022,** enforce **Extended Producer Responsibility (EPR),** holding producers accountable for collection and recycling. Similarly, **Bio-Medical Waste Management Rules,** 2016, ensure safe handling and treatment of healthcare waste, while **Construction & Demolition Waste Management Rules, 2016,** prioritize reuse and recycling of C&D debris. These policies, if implemented optimally, can push for a circular economy, minimizing landfill dependence, and promoting sustainable waste treatment and processing.

How far are we with treatment? According to the CPCB report of 2022-23, 2,474 dumpsites have been identified across the country. **Of these, only 377 have been reclaimed/capped, and a mere 44 have been converted into sanitary landfills.** Noting this, MoHUA introduced Dumpsite Remediation Accelerator Programme **(DRAP)** in 2025. It covers 200 Urban Local Bodies (ULBs) for **100% remediation of 214 most critical dumpsites across India**.

This small number of reclaimed dumpsites for conversion to landfills shows that the urgent need to address the issue of unmanaged waste is undeniable. Given the significant environmental and health hazards posed by existing dumpsites, there must be a concerted effort to carefully treat the legacy waste in these areas. The primary goal should be to transform all such unmanaged sites into scientific, sanitary landfills to be able to carry out safer disposal and treatment.

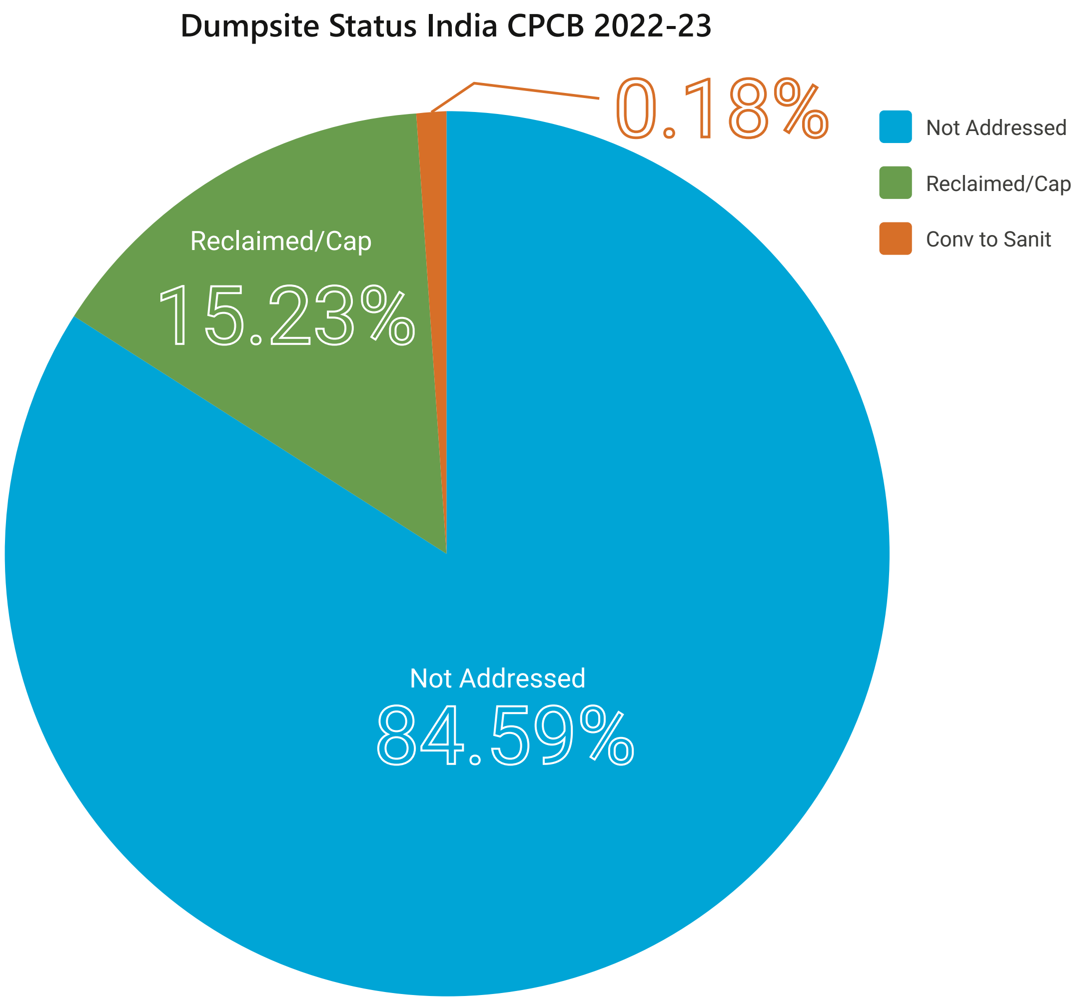


Figure 16: Status of identified dumpsites in India, 2022-23

(Source: CPCB)

1.4.5 Processing

Waste processing in India is a critical component of the broader waste management framework, addressing the country's growing MSW challenge. Each component of MSW can be processed to recover it. Methods employed include composting for organic waste, bio methanation to produce biogas, incineration for energy recovery, and recycling, primarily facilitated by both formal and informal sectors.

Despite this existence of facilities for processing waste, significant challenges persist, which occur at earlier stages of the value chain such as lack of adequate infrastructure, inefficient segregation practices, and a heavy reliance on landfilling that hinder the authorities' ability to carry out processing efficiently. This is where government initiatives like the SBM and the **SWM Rules 2026** aim to come in and enhance processing efficiency through mandated improved source segregation, integration of informal waste workers into formal systems, and promotion of sustainable practices.

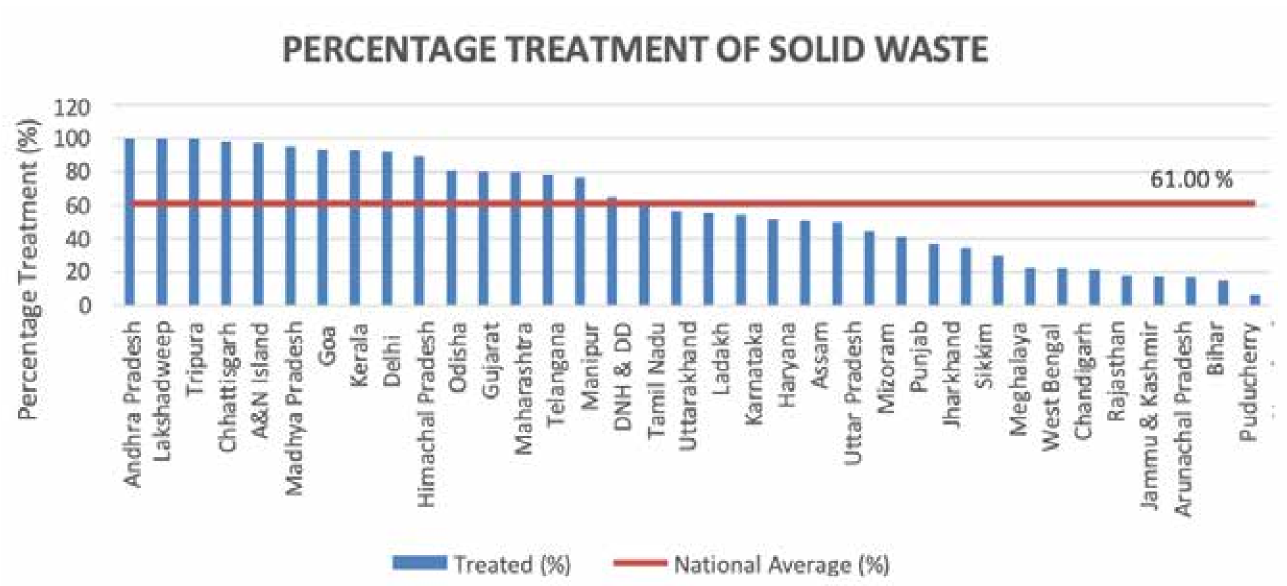


Figure 4: Share of solid waste treated across states and union territories in India, 2022-23

(Source: CPCB)

As per the data from CPCB 2022-23 a total of 104,216 TPD of waste is processed or treated, which equates to **61% of the total waste generation.**

The number of dumpsites can be significantly reduced by prioritizing waste segregation and treatment at the source. Given India's diverse geographical and socio-economic conditions, a uniform approach to waste management is not feasible. Each region requires a unique, localized solution that considers its specific waste patterns and local population. This makes public awareness and participation as critical as the technical aspects of waste management. By replicating successful, localized models, waste processing can be improved, helping to reclaim dumpsites and minimize the waste sent to landfills.

Vengurla, a small costal town in Maharashtra, adopted two bins-two bags – green for biodegradable waste and blue for non-biodegradable waste – approach for source segregation. Sanitary waste and domestic hazardous waste were collected separately. The council's choice of technologies and systems – from vermicomposting and biomethanation for kitchen waste and organic waste converter for fish or meat and fibrous wastes, to briquetting for biomass and green foliage waste – can be easily incorporated in any kind of urban centre, irrespective of the size of the population or the area. The city processes 100 per cent of the organic waste that is generated.

Source: UNDP

1.4.6 Challenges and Sustainable Solutions for Waste Management

The waste management cycle presents a multitude of challenges, necessitating strategic policy interventions across various stages. Despite these complexities, several cities have demonstrated commendable performance in specific aspects of urban waste management, serving as exemplary models for improved practices. A concise summary of these successful initiatives is presented in the table below.

Table 13: Challenges, Regulatory focus and Implementation Priorities across the waste value chain

Waste Value Chain Stage	Key System Challenges	Current Policy & Regulatory Focus (SWM Rules, 2026)	Implementation Priorities & Additional Actions	Illustrative Indian Practices
Waste Collection & Transportation	– Inconsistent collection and underdeveloped systems. – Financial constraints and technological deficits. – Lack of skilled labour and systematic implementation – Segregated waste is often remixed during collection and transport.	– Mandatory door-to-door collection and four-stream segregated collection. – GPS-enabled monitoring of collection fleets in cities with populations exceeding five lakh – Registration of informal waste workers and strengthened accountability mechanisms.	– Ensure segregation is preserved throughout collection and transportation through compartmentalised vehicles, anti-mixing clauses and strengthened collection contracts. – Improve monitoring through CCTV/photo-log verification at transfer stations and effective GPS utilization. – Adopt terrain-sensitive collection models for hilly, remote and dense settlements. – Integrate worker registration with existing NAMASTE databases and strengthen capacity building.	**Ambikapur (Chhattisgarh):** Adopted a zero-landfill model ensuring maximum waste is treated scientifically. **Pune (Maharashtra):** Launched the Red Dot campaign for managing sanitary waste through community engagement. **Indore (Madhya Pradesh):** Implemented 100% door-to-door collection, leading to high segregation rates. **Bengaluru (Karnataka):** Utilized ICT solutions for monitoring waste management services effectively.
Waste Segregation & Generator Responsibility	– Low compliance with mandatory source segregation. – Contamination of recyclables and organic materials. – Mixed waste disposal and open burning. – Limited awareness and inadequate collection pathways for special-care waste.	– Mandatory four-stream segregation at source. – Extended Bulk Waste Generator Responsibility (EBWGR). – Environmental compensation for non-compliance and strengthened generator responsibilities.	– Strengthen implementation through stakeholder-specific IEC campaigns, multilingual guidance and dedicated budgets. – Build sustained awareness and capacity across households, BWGs and collection agencies. – Establish dedicated collection pathways and drop-off kiosks for special-care waste. – Improve compliance through behavioural change alongside enforcement.	Alappuzha (Kerala): Focused on source segregation as a primary step in effective waste management.**Mysuru (Karnataka):** Achieved high rates of source segregation through community involvement and awareness programs.**Panaji (Goa):** Achieved 99% waste segregation at source through long-term citizen engagement, allowing for 80% of waste to be processed.

Waste Value Chain Stage	Key System Challenges	Current Policy & Regulatory Focus (SWM Rules, 2026)	Implementation Priorities & Additional Actions	Illustrative Indian Practices
Waste Disposal & Treatment	– Continued dependence on legacy dumpsites and landfills. – High environmental and public health risks. – Limited markets for recovered materials from biomining. – Landfill gas emissions and poorly engineered disposal facilities.	– Time-bound legacy waste remediation through DRAP. – Scientific landfill standards and stronger restrictions on landfilling. – Emphasis on scientific disposal and environmental safeguards.	– Strengthen market linkages for biomining outputs, RDF and recovered materials before remediation projects are undertaken. – Improve landfill gas capture, monitoring and environmental compliance. – Expand remediation support beyond DRAP-covered sites and promote scientific disposal through market-ready recovery pathways.	**Taliparamba (Kerala):** Established a model for converting organic waste into biogas, reducing landfill dependency. **Chandrapur (Maharashtra):** Remediated legacy waste through biomining, converting the land into an integrated waste treatment facility.
Waste Processing, Recovery & Circular Markets	– Insufficient processing facilities. – Inefficient segregation practices hinder processing efficiency. – Heavy reliance on landfilling for unprocessed waste. – Weak market linkages and inconsistent authorization of processing facilities.	– Promotion of decentralized processing, resource recovery and higher RDF utilization. – Strengthened responsibilities for waste processors, ULBs and bulk waste generators. – Support for multiple waste processing pathways.	– Standardize authorization and approval mechanisms for processing facilities and integrate SPCB-ULB systems. – Improve MRF viability through market development support and assured off-take. – Position Waste-to-Energy only for non-recyclable residual waste after segregation and material recovery. – Strengthen demand for compost, RDF and recovered materials through market-based interventions.	**Surat (Gujarat):** Implemented a comprehensive waste treatment system that includes multiple processing technologies. **Kakinada (Andhra Pradesh):** Developed a robust system for converting organic waste into biogas using advanced technologies. **Jamshedpur (Jharkhand):** Established a biomethanation plant to convert organic waste into energy efficiently.Mysuru (Karnataka): Developed a decentralized composting system that processes wet waste locally to reduce transport costs.

1.4.7 Overarching Challenges in Waste Management

Methodological and Technological Gaps

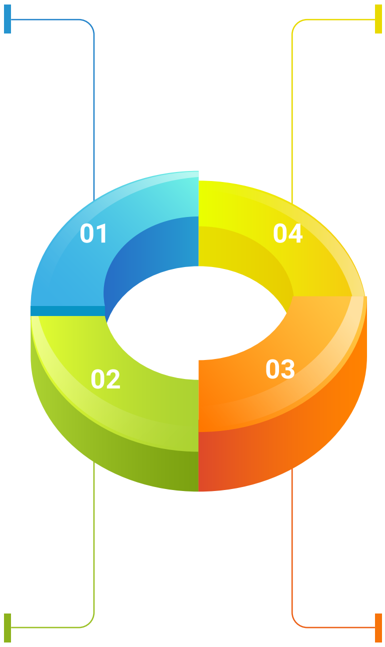
Limited Waste Characterisation: Regular waste characterisation studies remain absent across most Urban Local Bodies (ULBs), resulting in poor understanding of waste composition, calorific value and organic content. This affects technology selection, processing efficiency, methane estimation and infrastructure planning, while also limiting evidence-based implementation of the SWM Rules, 2026.

1. Data Limitations and Discrepancies

India's SWM system is plagued by significant data limitations and discrepancies, which make it difficult to accurately assess the situation and formulate effective policies. These issues stem from fragmented reporting, a lack of standardized methodologies, and an inability to account for all waste streams.

Unaccounted Waste: A key indicator of data limitations is the large amount of waste that remains unrecorded. The **CPCB Annual Report 2022-2023** reveals that a staggering **17%** of the total waste generated in the country, amounting to **28,576 TPD,** is "unaccounted for".[54] This waste is often disposed of in unscientific dumpsites, where it poses environmental and health risks.

Inconsistent Reporting: Data submitted by SPCBs and ULBs is often inconsistent, as even seen in the previous section- some states fail to submit their data, hindering the CPCB's ability to create a reliable national picture of waste management. This is due to a lack of real-time monitoring and a reliance on outdated surveys.[55,56]



Informal Sector: The vital role of the informal sector—including waste pickers and scrap dealers—in collecting and recycling waste is largely unrecorded. This leads to an underestimation of recycling rates and an overestimation of the waste that ends up in landfills, creating a distorted view of the SWM landscape.[57]

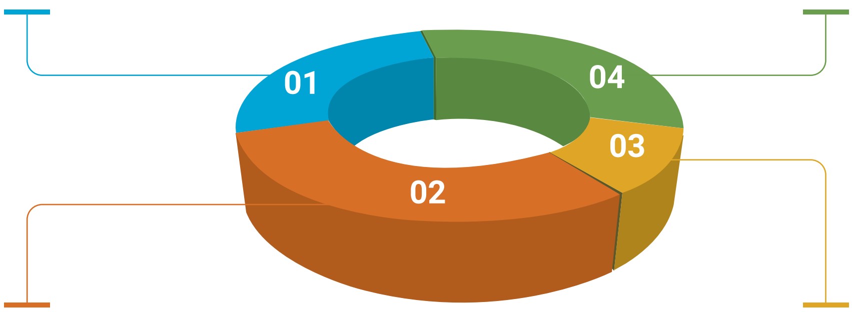
Missing Historical Data: The absence of comprehensive historical data on waste generation, composition, characterisation and landfill records hampers accurate methane emission modeling. This forces experts to rely on assumptions and extrapolations, which can lead to significant variations in estimates.[58]

2. Methodological and Technological Gaps

Current SWM and emissions modeling methodologies are often ill-equipped to handle the unique characteristics of the Indian context, leading to inaccurate assessments and inefficient practices.

Inapplicability of Global Models: Many established methane estimation models, such as those from the Intergovernmental Panel on Climate Change (IPCC), were developed for sanitary landfills in industrialized nations. The lack of comprehensive data makes these models unsuitable for developing countries like India, which primarily use open dumpsites. The aerobic conditions, inadequate leachate management, and frequent fires in these dumpsites result in different decomposition patterns and emissions than those predicted by standard models.[59]

Lack of Standardization: Methodologies for waste collection, management, and reporting vary significantly across regions. Standardizing national methodologies is crucial to enhance data reliability and unify national estimates, which is currently a major challenge.[61]



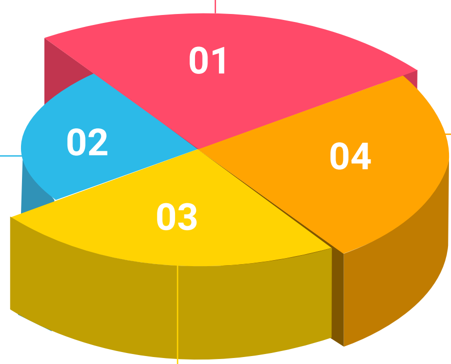
Failure to Account for the Informal Sector: Methodologies for waste data collection do not adequately account for the significant contribution of the informal sector. As a result, the amount of waste actually being recycled and diverted from landfills is likely higher than what official reports suggest, but the precise amount remains unknown due to a lack of formal data collection from this sector.[60]

Technological and Infrastructural Deficiencies: India's SWM infrastructure is often inadequate, with only about 60% of the total MSW being treated. There is a critical need for indigenous technologies for waste analysis and processing, as emphasized by the CPHEEO. Limited access to advanced GHG measurement technologies further compounds the problem, leading to potential under- or overestimation of emissions.[62] This also limits progress toward **circular economy objectives and landfill diversion targets emphasized under the Solid Waste Management Rules 2026.**

3. Emissions as a Challenge

The waste sector is a rapidly growing contributor to India's GHG inventory, primarily through the emission of methane (CH_4). The management of these emissions is a major hurdle in the country's climate mitigation efforts.

Growing GHG Contribution: According to India's **1st Biennial Transparency Report (BTR-4),** the waste sector contributed approximately **2.76%** of the country's total GHG emissions in 2022. This sector is one of the fastest growing in terms of emissions, with a **51.21%** increase from 2005 to 2022, driven by urbanization and a rising population[63]



Open Burning: The practice of open waste burning further exacerbates the emission problem. **BTR-1** highlights that open burning and incineration contributed **0.5% of GHG** emissions of waste sector in 2022[64]

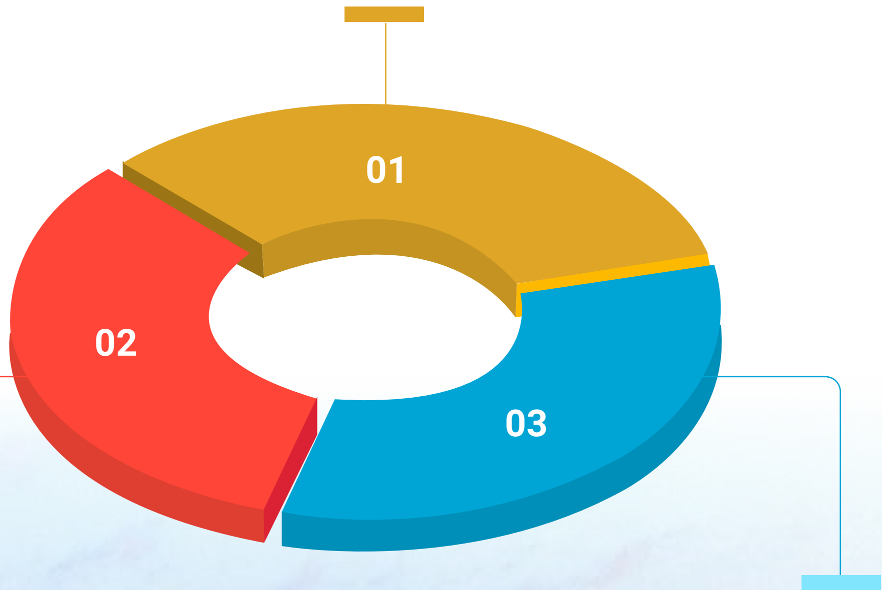
Methane Emissions: Municipal solid waste in India has a high organic content (40-60%), which, when left to decompose in unscientific dumpsites, generates substantial amounts of methane[65]

Inadequate Monitoring: A key challenge is the lack of effective monitoring of methane fluxes from existing dumpsites and leaks from treatment plants by ULBs. This lack of real-time data makes it difficult to pinpoint the sources of emissions and implement targeted mitigation strategies[66]

4. Enforcement as a Challenge

Fragmented Institutional Coordination: Enforcement responsibilities are distributed across multiple agencies, including ULBs, SPCBs, CPCB and state departments. Limited coordination, overlapping responsibilities and inconsistent information sharing often delay approvals, inspections and corrective actions, reducing the overall effectiveness of waste management governance.

Weak Implementation: Although the CPCB and the MoEFCC are the nodal agencies for environmental regulation, the implementation of their rules is often weak at the local level. The crucial practice of 100% waste segregation at the source, as mandated by law, is rarely achieved.



Financial and Infrastructural Gaps: Many ULBs lack the necessary financial resources to implement effective SWM services. Their revenues and expenditures have stagnated, making it difficult to invest in the required infrastructure and technology, and to hire and train enough personnel.

Informal Sector Integration: The crucial role of the informal waste sector is not formally recognized or integrated into the SWM system. This makes it difficult to regulate their activities, ensure worker safety, and leverage their potential to improve waste management and enforcement.

CHAPTER 2:

LANDFILLS, DUMPSITES, AND CLIMATE IMPACT OF THE INDIAN MUNICIPAL SOLID WASTE SECTOR

2.1 Landfill vs Dumpsites: Critical Distinctions for Municipal Solid Waste Management

This chapter explores the landscape of landfills and dumpsites in India, establishing clear distinctions between the two and providing conceptual clarity on their roles within waste management. It then traces the current structure and status of waste disposal across the country. Further, the chapter highlights the grave climate, environmental, and public health consequences associated with the unchecked expansion of dumpsites. It underscores the critical importance of reliable data and monitoring systems while drawing attention to the persistent shortcomings and systemic gaps that undermine effective waste management.

2.1.1 Dumpsite vs. Sanitary Landfill

Landfilling is the final placement of waste into or onto the land in a controlled way.[67]

A dumpsite is an unregulated area where waste is simply deposited, while a sanitary landfill is a scientifically engineered facility designed to minimize environmental harm during waste disposal.[68]

The structure of a sanitary landfill is composed of multiple protective layers and systems. At the base, a composite liner of compacted clay and synthetic geomembrane (such as high-density polyethylene) prevents leachate from contaminating groundwater. Above this, a leachate collection network of drainage layers, pipes, and pumps removes the toxic liquid produced as waste decomposes. Gas collection systems are installed to capture methane and other landfill gases, both for safety and for potential energy recovery. Each day, the waste is covered with soil or alternative material to minimize odors, pests, and fire risks, and once the landfill reaches capacity, a final cover or cap—comprising impermeable layers, drainage, and soil—seals the site and prepares it for future restoration.[69]

The following table summarizes the key differences between both methods of disposal. As of now, 44 of India's active dumpsites have been converted to sanitary landfills, while 377 have been reclaimed/capped - an alarming 2474 dumpsites still remain.[70]

Table 14: Distinctions between a Dumpsite and a Sanitary Landfill

Feature	Dumpsite	Sanitary Landfill
Regulation	Unregulated	Regulated and engineered
Design	Unmanaged, simply a dumping ground	Scientifically designed, layered, and compacted
Environmental Impact	High (pollution, disease, etc.)	Low (controlled emissions and leachate)
Public Health	Significant health risks	Minimized health risks
Leachate	Uncollected, contaminates groundwater	Collected and treated
Gases	Released directly into the atmosphere	Captured and/or managed

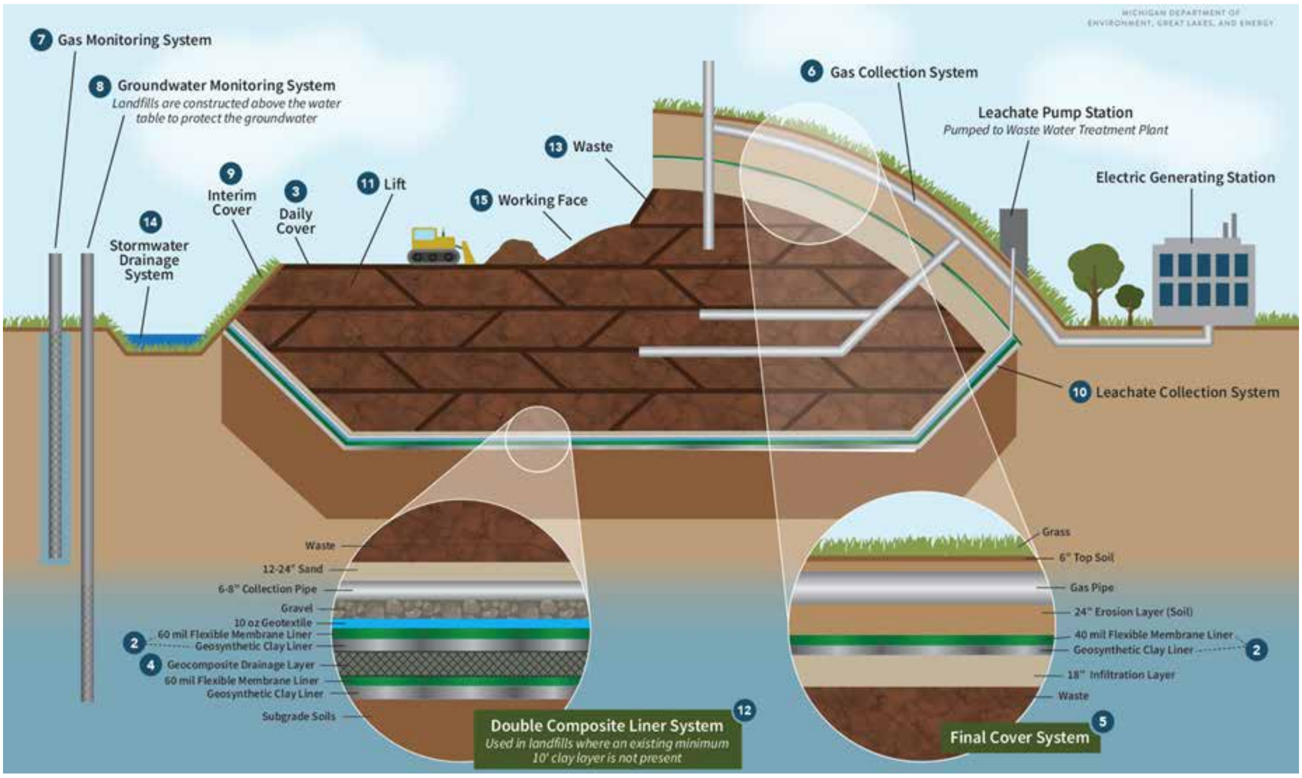


Figure 18: Schematic of an engineered sanitary landfill
(***Source:*** *Michigan Department of Environment)*

In India, CPCB's *Guidelines and a Checklist for evaluation of MSW Landfills*[71] create the foundation for landfill site selection and management, providing necessary guidance for operational infrastructure and environmental safeguards. The same guidance stipulates that **each landfill site shall be designed for 20-25 years and with proper documentation of a phased construction and closure plan.**

The government, under the SBM advisory, notes that solid waste dumps which have reached their full capacity or those which will not receive additional waste should be closed and rehabilitated by bio-mining and waste processing followed by placement of residues in new landfills or capping. Capping is further detailed as: with solid waste cover or solid waste cover enhanced with geomembrane to enable collection and flaring / utilization of GHGs or the same with additional measures (in alluvial and other coarse-grained soils) such as cut-off walls and extraction wells for pumping and treating contaminated ground water. The advisory allows for "any other method suitable for reducing environmental impact to acceptable level."[72]

2.1.2 Dumpsites in India

As per CPCB 2022-23, India reported a total of **2474 active dumpsites, 377** reclaimed/capped dumpsites, and a mere 44 dumpsites converted to sanitary landfills – notably 35 out these 44 were in the state of Punjab. The worst performing states, with over 200 dumpsites, are **Maharashtra, Rajasthan, Tamil Nadu, and Karnataka.**

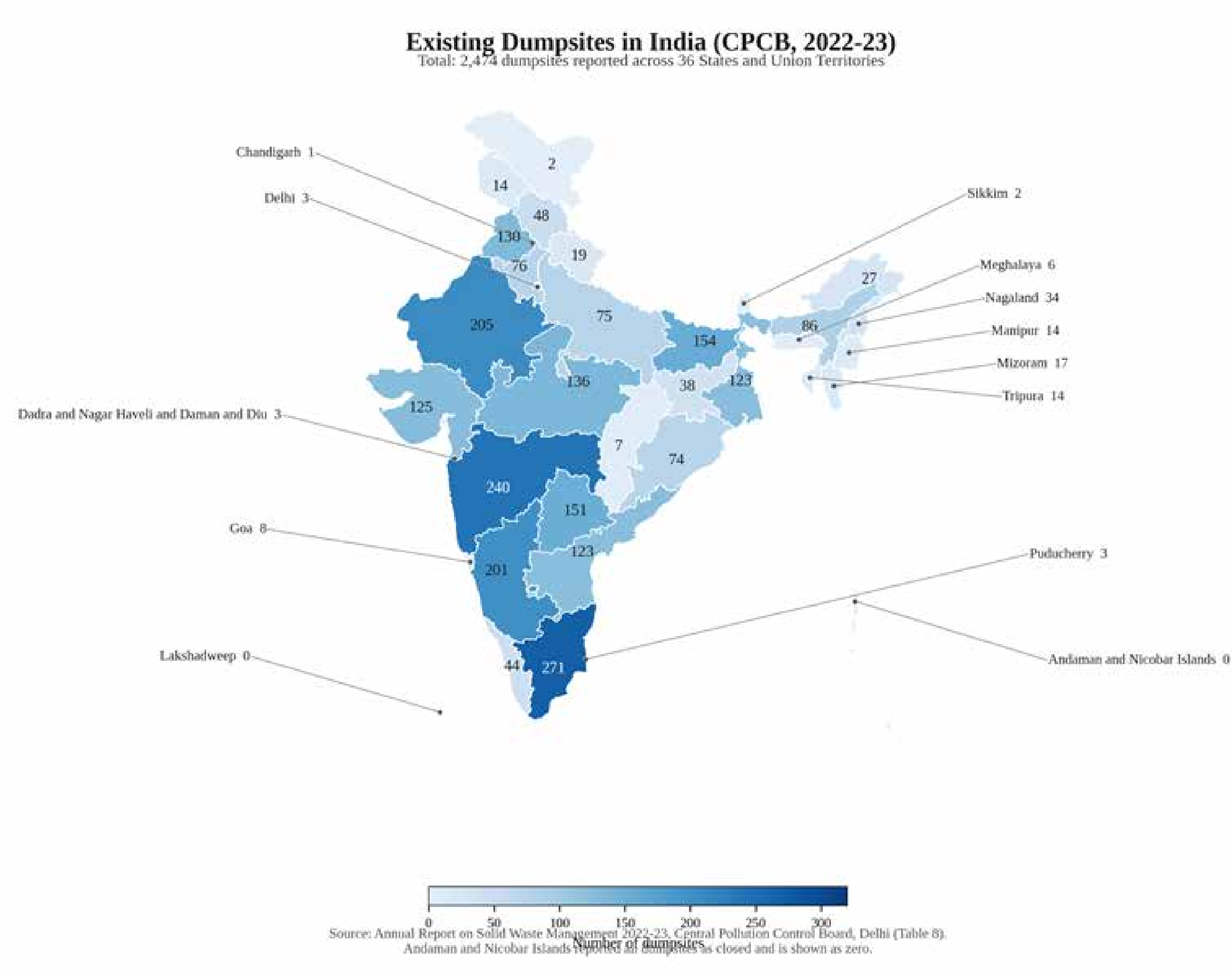


Figure 19: Number of dumpsites reported by state, CPCB 2022-23

Interestingly, the SBM Dashboard (as of July 2026), reports a contrasting picture with a total of **2454 active dumpsites –** with **Maharashtra, Uttar Pradesh, Tamil Nadu, and Karnataka** showcasing the most alarming picture.

While the set of critical states remains largely consistent across both sources, the maps also reveal a clear dispersion in the absolute values. E.g., Uttar Pradesh has more than double the number of dumpsites in SBM as opposed to CPCB figures; or, that Assam has triple the dumpsites as per CPCB, as compared to SBM dashboard. The difference in two maps presents a clear case of **inadequacy in reporting and data management** regarding dumpsites, even at the central government level.

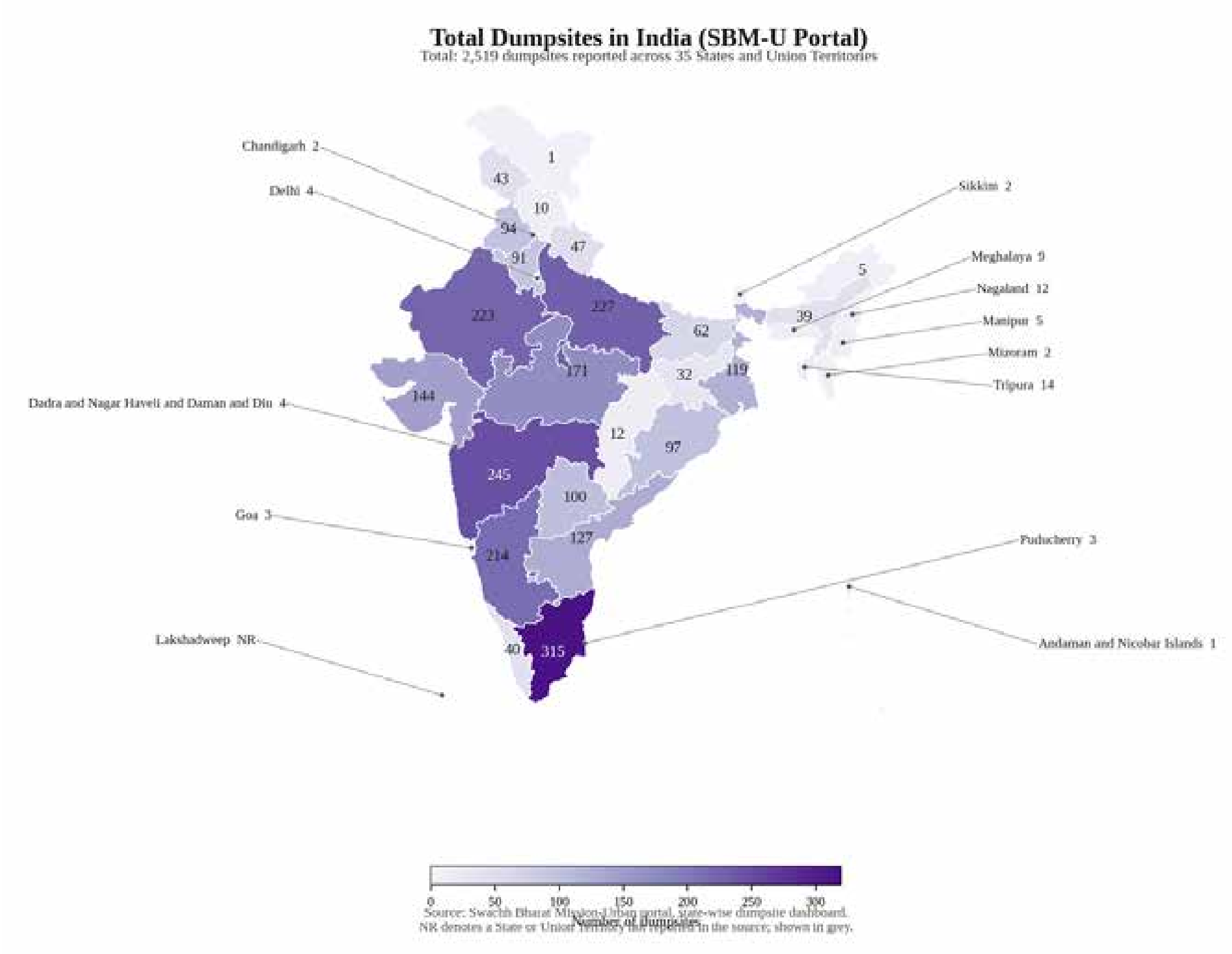
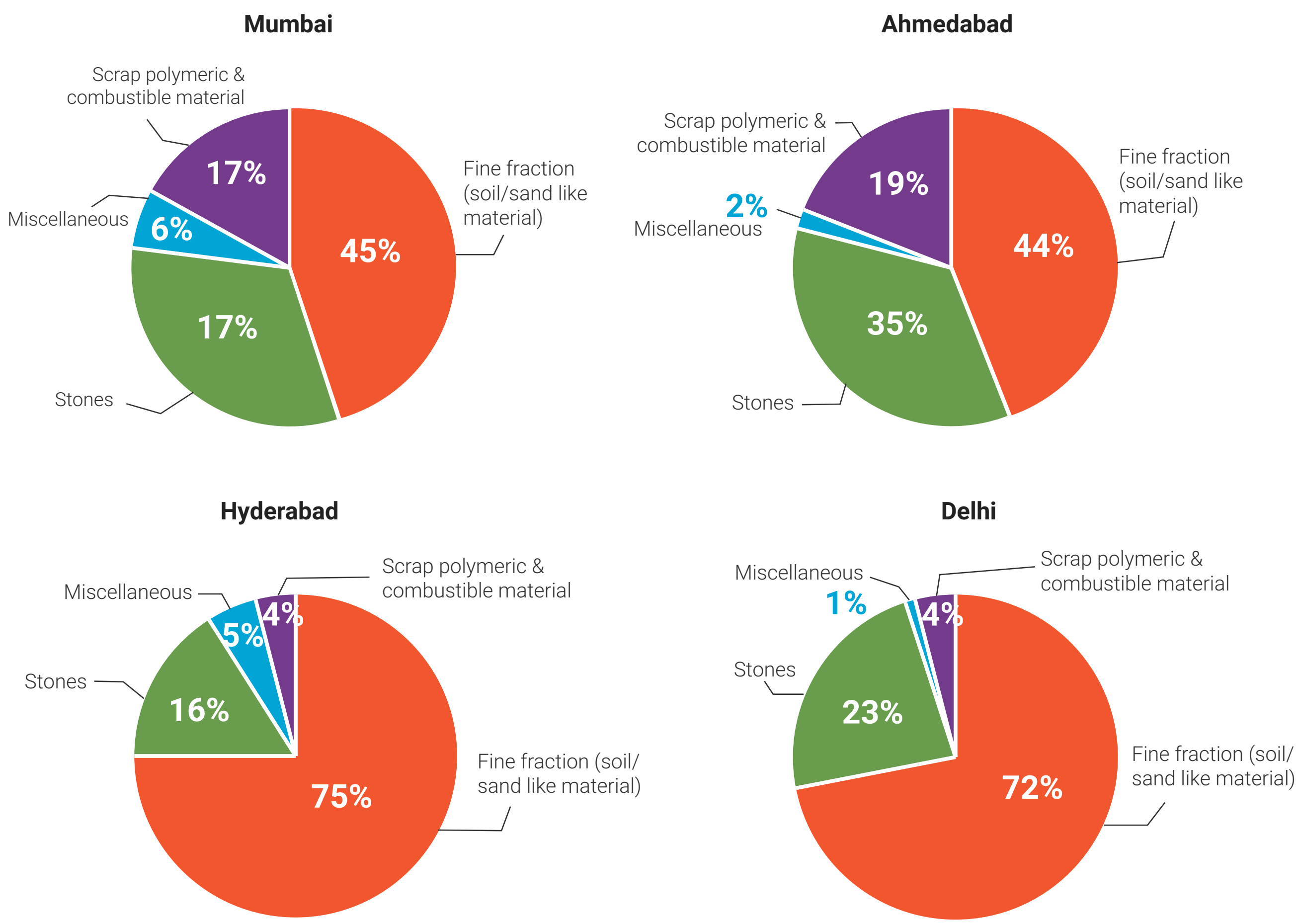


Figure 20: Number of dumpsites reported by state, SBM-U Portal, 2026

2.1.2.1 Legacy Waste ~ *A Humiliating Inheritance*

Due to the years of disposal of untreated MSW, **a large quantity of waste has accumulated in unsanitary dumpsites – this is referred to as legacy waste.** Although the term "legacy waste" has not been defined in any official government document in India, it typically refers to **aged municipal solid waste in landfills or dumpsites.** There is no information on how old the waste must be in order to qualify to be called legacy waste. Legacy waste is a mix of partially or completely decomposed biodegradable waste, plastic waste, textiles, metals, glass and other components.

For the purposes of this report, the term is used as an operational definition referring to historically accumulated waste deposited at dumpsites prior to the implementation of systematic waste processing and scientific landfill management practices. This working definition broadly aligns **Solid Waste Management Rules 2026,** which that *"all legacy solid waste dumpsites to be biomined and bioremediated"*.[73] The definition used in this analysis is therefore intended primarily to support emissions estimation and scenario modelling in Chapter 4, while remaining consistent with the broader regulatory intent governing dumpsite remediation in India.



Source: Richa Singh, *Solidification and Stabilization of Hazardous Waste,* Department of Environmental Science and Engineering, IIT Bombay; Somani, M. et al., Elsevier, 137, pp. 82–92; and Singh, A. and Chandel, M.K., 2020, Elsevier, 134, pp. 24–35

Figure 21: Composition of legacy waste at selected Indian dumpsites
(Source: *Centre for Science and Environment)*

The composition and characteristics of legacy waste are different from that of fresh MSW, due to the various reactions that the waste undergoes over the years – lying dormant in the dumpsites. Examples would be microbes reacting with organic waste through **acetogenesis**, **acidogenesis** and **methanogenesis**.[74] Research identifies the following general composition:

01
Fines (40–60%): Decomposed organic matter mixed with silt, sand, and fine C&D waste fragments.

02
Combustible materials (15–20%): Plastics, paper, cardboard, textiles.

03
Coarser inert materials (about 20%): Broken bricks, masonry, stones.

04
Miscellaneous (1–5%): Metals, glass, hazardous sharps, sanitary waste.

The proportion of these components varies by region and age of the dumpsite. For example, older dumpsites in Delhi and Hyderabad have higher fines (~75%) due to extensive organic degradation.[75]

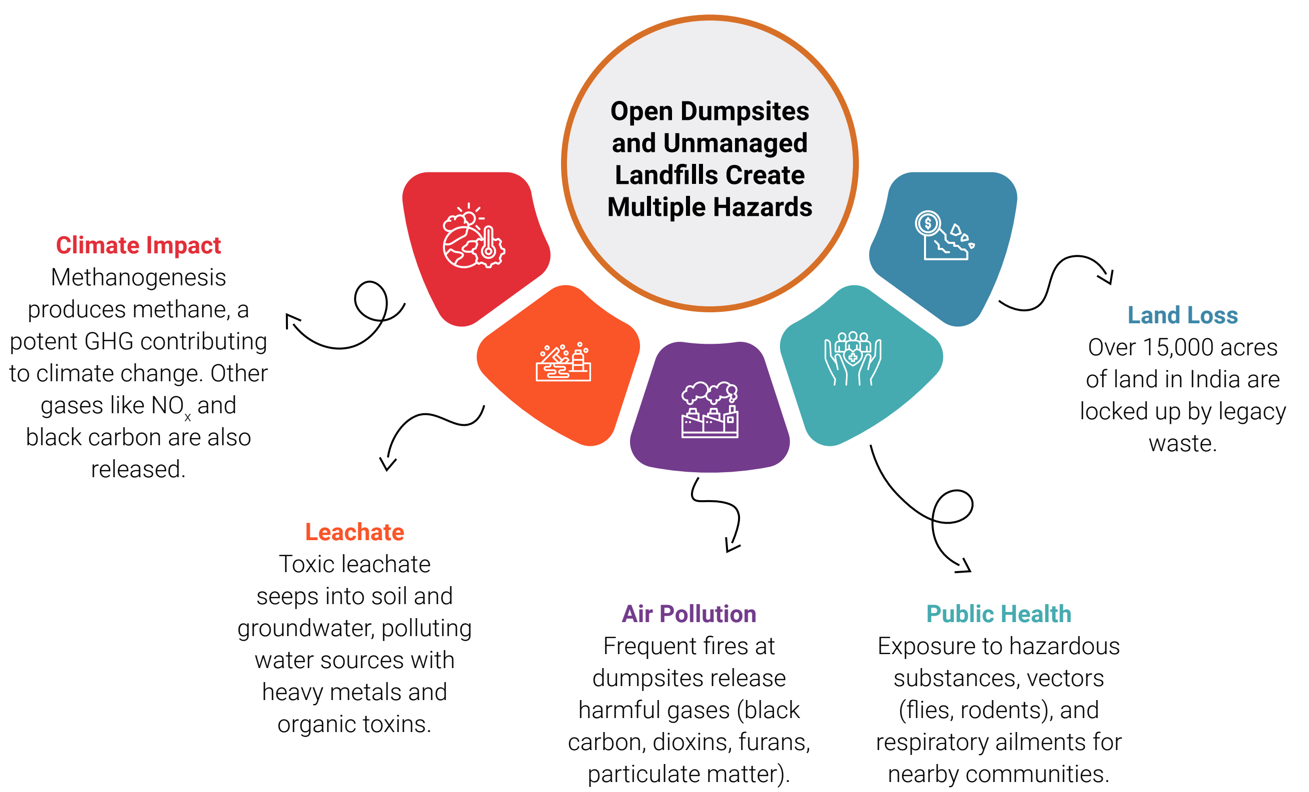
2.1.2.2 Landfill and Dumpsite Statistics in Perspective

As per the SBM Dashboard (as of May 2026), **India is burdened with roughly 2700 lakh tons of legacy waste lying across more than 15,000 acres of dumpsites.** This means that legacy dumpsites in India occupy an area equivalent to approximately **8,500 FIFA-standard football fields,** a number that will continue to grow unless the treatment of fresh waste and remediation of legacy waste keep pace with the country's accelerating waste generation.

2.1.3 Why Focus on Landfills and Dumpsites? Climate, Pollution, and Public Health Linkages

One of the most critical yet often overlooked consequences of improper SWM is its contribution to climate change. When organic waste is dumped in landfills or open dumpsites without proper treatment, it decomposes anaerobically (without oxygen), resulting in the release of methane gas.[76] Methane is a GHG that is 80 times more potent than carbon dioxide in trapping heat in the atmosphere over a 20-year period.[77] Globally, methane emissions from human activity are responsible for nearly 45% of current net warming, and curbing these emissions could avert nearly 0.3°C of global warming by 2045.[78] The waste sector, through landfill and dumpsite methane, is one of the highest emitting sectors in the world and India is among the world's highest emitters of methane from landfills, with sites like Delhi's Ghazipur - which in 2021 alone, leaked 156 tonnes methane per hour comparable to pollution from 24 million cars running at once.

The subsequent health impacts on people living near these sites are also profound. Residents are exposed to increased risks of respiratory diseases, asthma, infections, and other health issues due to polluted air and water. Landfill fires, often sparked by the buildup of methane and high temperatures, exacerbate these problems by releasing clouds of toxic smoke. Additionally, open dumpsites serve as breeding grounds for disease-carrying pests like mosquitoes and rodents, further increasing the risk of vector-borne diseases.



MSW is made up of different organic and inorganic fractions like food, vegetables, paper, wood, plastics, glass, metal, and other inert materials. In cities, it is collected by the municipalities and transported to designated disposal sites.[79] When MSW is first deposited in a landfill, dumped organic waste undergoes an aerobic (with oxygen) decomposition stage when little methane is generated. Then, typically within less than 1-year, anaerobic conditions are established, and methane-producing bacteria begin to decompose waste and generate methane.[80] The amount of methane produced depends on several factors, including type of waste, disposal method, and environmental conditions. The longer the waste is disposed of in these areas, the higher the emissions from the dumpsite - this highlights the impact of legacy waste.

As the anaerobic reactions with fresh and legacy waste persist, large dumpsites with copious volume of waste become hotspots for methane generation. The potency of the heat signal from methane is so high that it is detected by satellites as well. Hence, dumpsites are often characterized as **methane plumes.**

Another GHG released from landfills and dumpsites is nitrous oxide or N_2O, primarily generated from aerobic processes during leachate treatment. Bioreactor landfills emit more N_2O than traditional anaerobic landfills. This gas persists in the atmospheric lifetime of approximately 114 years and a Global Warming Potential (GWP) of 273 over 100 years, becoming an even more potent heat emitting gas.

Waste that is lying unattended can often be a major risk to health. Toxic chemicals can leak from materials that are dormant in landfills for longer periods or ones that are burnt in improper surroundings, contaminating resources like soil, water, and air, that would eventually interact with and/or be consumed by human beings and have malignant effects on their well-being. Untreated waste, in land and water, is a breeding ground for microbes that cause illnesses and diseases amongst humans. From the public health point of view, improper solid waste management often attracts insect and rodent vectors which facilitate the spread of diseases such as cholera, malaria, diarrhea, and dengue fever.

Most vulnerable are the workers actively spending their time managing these dumpsites and landfills, followed by residents in the proximity of these sites. The livelihoods of these people are intertwined with these toxic landfills as they work in conditions with no protective equipment and without any social protection. They breathe toxic air, risk fire and explosion exposure, and are injured or killed when unstable parts of such man-made garbage mountains collapse. Many cases have been reported in recent years itself, including a worker being buried in Bandhwari, skin, eyes and respiration diseases for waste workers in Delhi and Ahmedabad, and prolonged heat exposure around the country.

Beyond climate pollution, methane also reacts with the atmosphere leading to spontaneous combustion – often termed dumpsite fires. These fires can often get out of control and take hours to contain – indicating severe risk for human life. Case in point, the Bandhwari landfill in Gurugram has reported 4 incidences of methane-induced fire incidents in the month of April 2025, some of which lasted over 20 hours and took 25 fire trucks and 40 firefighters on the ground to battle the blaze. Fire department officials were quick to point out that such fires were not uncommon to see in landfills during summer months.[81]

These fires not only are a threat to human life and health but also become sources of large releases of black carbon. Commonly known as soot, it is a component of $PM_{2.5}$ and an SLCP with a lifespan of two weeks and a warming potential of 52,000 in that timeframe. This makes it a harmful air pollutant and heat stress aggravator simultaneously.

Some studies from Indian cities highlight the severity of health hazards caused due to improper waste management. One of the most infamous dumps is the Ghazipur dump near New Delhi, spanning an area larger than the Taj Mahal covers. On March 22, 2022, the Ghazipur dump leaked an estimated 2.17 metric tonnes of methane in an hour.[82] Besides causing fires, pollution and landslides, the landfill is also a breeding ground for tuberculosis and dengue.

The Deonar landfill in Mumbai, India is Asia's largest dumping ground – the size of 268 football fields. Nine thousand metric tonnes of waste ends here daily but the litter neither undergoes segregation nor processing. The stench and smoke from the garbage are the cause of many heart and respiratory diseases in people living in the nearby slums.[83]

An extremely toxic component released from landfills or dumpsites is leachate - a contaminated liquid formed when water percolates through waste materials, such as landfill deposits, dissolving and carrying a complex mixture of pollutants including organic compounds, heavy metals, ammonia, and pathogens. This liquid poses serious environmental and health risks, particularly through contamination of groundwater and surface water, soil pollution, and spreading of toxic substances.

2.1.3.1 Spotlight: Leachate Impacts, Treatment Methods, and Composition Analysis

Leachate is a significant environmental hazard due to its potential to contaminate soil, groundwater, and surface water. Key impacts include:

Water Pollution: Leachate can infiltrate groundwater, introducing toxic substances and nutrients that disrupt aquatic ecosystems and render water unsafe for human consumption.

Toxicity: Acute and chronic toxicity to aquatic organisms and humans is a concern, given the presence of mutagenic and carcinogenic substances

Soil Contamination: Accumulation of heavy metals and persistent organics can degrade soil quality, hinder plant growth, and bioaccumulate in food chains

Odour and Aesthetic Issues: High organic content leads to foul odors and discoloration of water bodies near landfill sites.

But just like methane, even leachate can be managed properly using various techniques that have been summarized in the table below[84].

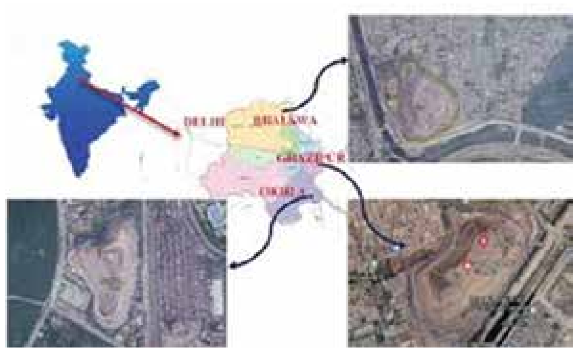
Table 15: Leachate treatment methods: description, advantages and limitations

Treatment Type	Description	Advantages	Limitations
Physical	Includes sedimentation, filtration (sand, activated carbon), membrane technologies (microfiltration, reverse osmosis), and air stripping to remove suspended solids, particulates, and volatile contaminants like ammonia.	Effective removal of suspended solids and particulates; membrane tech can remove dissolved salts and heavy metals; air stripping efficiently removes ammonia (up to 90%).	Can be energy-intensive (especially air stripping); produces secondary waste or off-gases requiring further treatment.
Chemical	Uses precipitation, coagulation, and advanced oxidation to chemically transform or remove dissolved pollutants.	Targets dissolved contaminants effectively; can reduce toxicity and color; often faster than biological methods.	Requires chemical reagents; may produce sludge or secondary pollutants; operational costs can be high.
Biological	Employs aerobic and anaerobic microbial processes and constructed wetlands to biodegrade organic pollutants and remove nutrients.	Environmentally friendly; cost-effective; minimal secondary waste; capable of high removal efficiency for organics and nutrients.	Slower process; sensitive to environmental conditions (pH, temperature); inhibited by toxic substances; may need pre/post-treatment.
Phytoremediation	Uses plants (e.g., Lemna minor, Eichhornia crassipes) to uptake and degrade contaminants, especially heavy metals.	Low-cost; low energy consumption; can remove metals and organic matter; enhance groundwater recharge.	Longer treatment time; effectiveness depends on plant species and environmental factors; limited to certain contaminants.

Selecting the appropriate treatment depends on leachate composition, site conditions, regulatory standards, and cost considerations. Advances in membrane technology and integrated treatment systems are improving the efficiency and sustainability of leachate management, aligning with environmental protection and circular economy principles.

Compositional Breakdown of leachate in different landfills of Delhi[85]:

Three landfill sites, Bhalswa, Okhla, and Ghazipur of New Delhi, were selected to determine the physicochemical properties, including significant metals of lowland leachate. Furthermore, the leachates from three different dumpyards have been compared with the permissible limits prescribed by Environmental Protection Agency, 1986. Thus, the present research findings focus for the Bhalswa landfill site leachate analysis, which indicated a high biochemical oxygen demand concentration of 3356 mg/L and chemical oxygen demand concentration of 5942 mg/L, respectively. However, the total dissolved solids, electrical conductivity, and ammonical nitrogen concentrations have been 12,384 mg/L, 32,600 µmho/cm, and 36.6 mg/L. It is observed that the Ghazipur landfill site was highly tainted as compared to Okhla and Bhalswa landfill sites. Further, quantitative analysis deduces the trend of heavy metals concentration of iron, nickel, zinc, arsenic, and chromium in the order of Bhalswa > Okhla > Ghazipur landfill sites. The toxicity hazard of dumpsites from Bhalswa, Ghazipur,



and Okhla was also examined using the leachate pollution index, and the values were obtained such as 21.57, 26.61, and 20.28, respectively. Additionally, the present study reveals that the leachate percolating through all the landfill sites exceeds the permissible limits prescribed by Environmental Protection Agency, 1986, and thus, an immediate attention is required to circumvent its other adverse effect on the nearby area and groundwater reserves.

2.2 In Focus: Indian Waste Sector's Contribution to GHG Emissions

India's waste sector is a rapidly escalating source of GHG emissions, predominantly methane, making it a critical area for climate action. This significant contribution stems from the growing volume of waste generated by population growth and urbanization, coupled with prevalent unscientific disposal practices.

2.2.1 National Waste GHG Profile

By 2030 and 2050, global GHG emissions from uncontrolled waste disposal systems are predicted to rise to 64% and 76% respectively.[86.] According to CPCB's Annual Report (2022–2023)[87], India generates approximately 170,939 tonnes of municipal solid waste per day (TPD). The reported gap of nearly 18% waste (>28,000 TPD) most likely ends up in unmanaged dumpsites or being subjected to open burning. To put this in perspective, **the gap in Indian waste management is roughly the same as the volume of waste that Australia generates in total everyday**[88]. This untracked portion is a major source of GHG emissions. Waste that decomposes or is openly burned releases methane, carbon dioxide, carbon monoxide, nitrous oxide, and black carbon, all of which contribute to climate change and air pollution. Even the 38,000+ TPD disposed of in sanitary landfills generates methane; and in the absence of leak-proof, well-managed gas collection systems, much of this methane is likely escaping directly into the atmosphere.

The waste sector experienced a growth of 51 per cent from 2005 to 2022, attributed to population growth, rapid urbanisation, and increasing waste generation. As per India's First Biennial Transparency Report (BTR1) to the United Nations Framework Convention on Climate Change (UNFCCC), India's total GHG emissions from the waste sector in 2022 were estimated at 93.84 $MtCO_2e$, representing 2.76 per cent of the country's total greenhouse gas emissions (excluding LULUCF).[89]

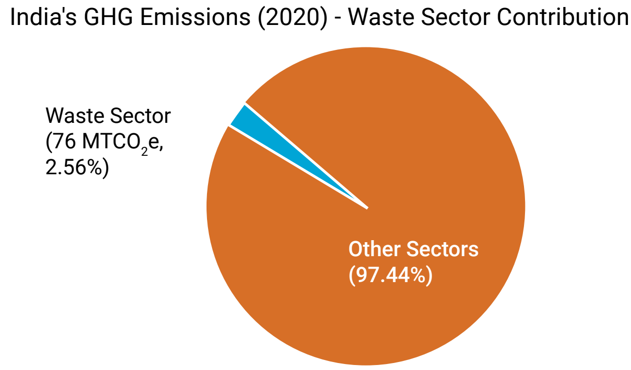


Figure 22: Share of the waste sector in India's total GHG emissions, 2022

(Source: *India's BTR-1)*

Table 16: Aggregated GHG emission estimates for the waste sector, 2005 and 2018[90]

Source Category	GHG Emission (Mt CO_2e) SAR GWP Values (2005)	GHG Emission (Mt CO_2e) SAR GWP Values (2018)	Percent change (2005–2018)	GHG Emission (Mt CO_2e) AR6 GWP Values (2005)	GHG Emission (Mt CO_2e) AR6 GWP Values (2018)	Percent change (2005-2018)
Waste	88.23	114.50	29.77%	110.20	142.92	29.69%
Solid Waste Disposal	7.05	13.23	87.66%	9.36	17.57	87.71%
Unmanaged Waste Disposal Sites	7.05	13.23	87.66%	9.36	17.57	87.71%
Wastewater Treatment and Discharge	81.18	101.27	24.75%	100.84	125.35	24.31%
Domestic Wastewater Treatment and Discharge	43.82	63.76	45.50%	51.21	75.77	47.96%
Industrial Wastewater Treatment and Discharge	37.36	37.51	0.40%	49.63	49.57	-0.12%

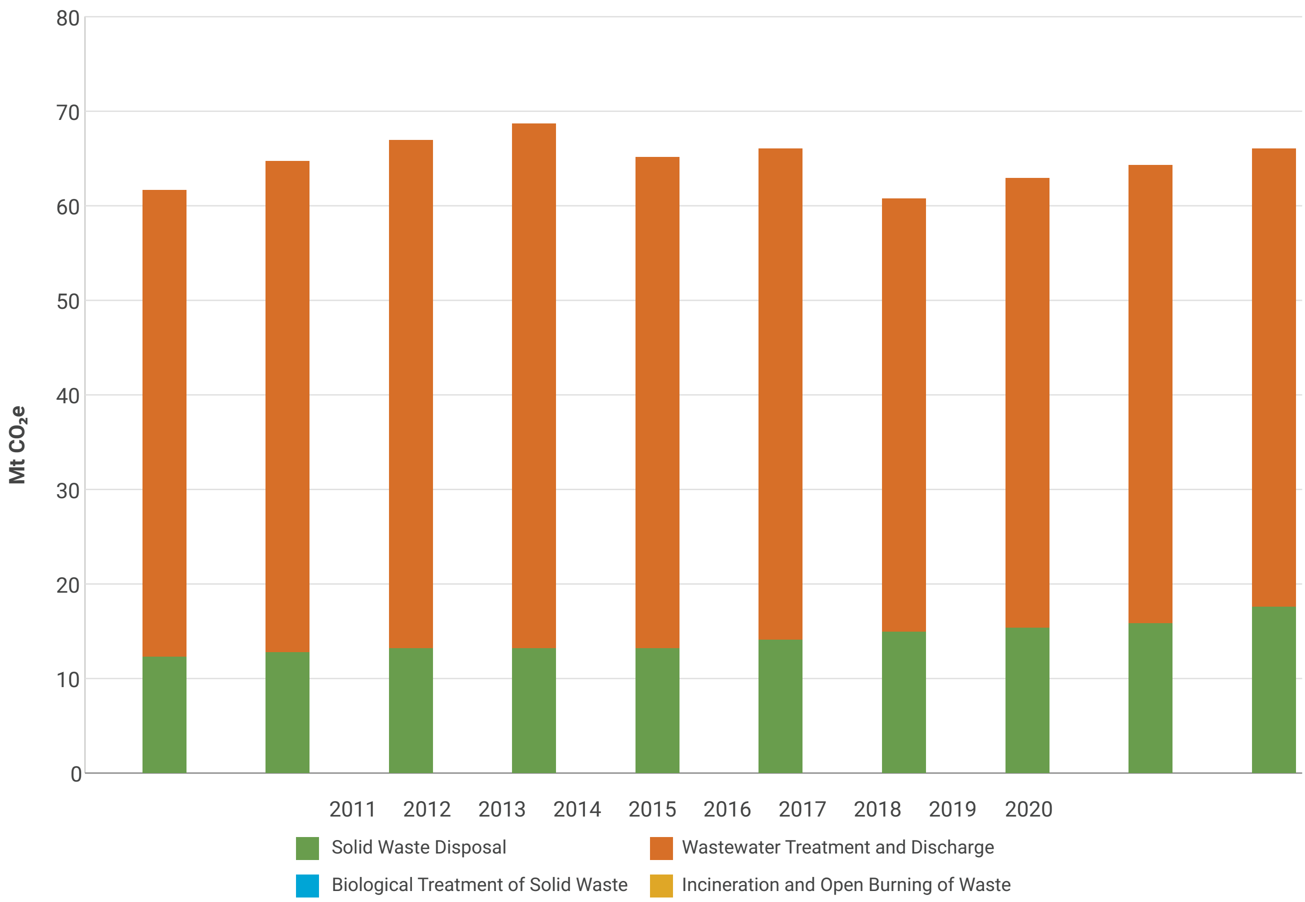


Figure 23: GHG emissions from the waste sector by subcategory, 2011 to 2020
(***Source:*** GHG Platform)

As per the BTR 1.0, **waste is the second highest source of methane (CH_4), with emissions** reported at 2776 Gg in 2022, following the agriculture sector. The waste sector is also a source of a significant amount of nitrous oxide (N_2O) emissions (58.93 Gg). It is also important to note the contribution of these emissions to climate change, and to understand the impact of these pollutants on the earth's temperature. Therefore, we have listed the global warming potentials (GWP) of CH_4 and N_2O over a period of 100 and 20 years as compared to the GWP of CO_2.

Table 17: Global warming potential of methane and nitrous oxide relative to carbon dioxide

Gas	GWP (20 years)	GWP (100 years)
CO_2	1	1
CH_4 (Methane)	~84	~30
N_2O (Nitrous Oxide)	~273	~265

Source: *CCAC*

The potency of **methane** and **N_2O** values as compared to CO_2 highlights the urgent need to curb these emissions, with increasing attention to the waste sector as it is a significant contributor to these emissions. Annual GHG emissions from MSW in India are expected to go up to 41.09 million tons by 2030[91], as opposed to 13.23 million tons in 2018[92] - presenting an **over 210% increase in 12 years.**

IGSD research clarifies that reduction of 'non-CO_2 climate pollutants' especially SLCPs, can help to:

- Avoid four times more global warming by 2050 than cutting CO_2 only;
- Decrease the rate of global warming by half; and
- Reduce projected warming in the Arctic by two-thirds

2.2.2 Non-CO_2 Emissions and the Waste Sector in India

2.2.2.1 Methane

The following sections provide a concise overview of the various pathways through which methane is emitted from the waste sector.

1. Solid Waste Disposal on Land:

The first way in which methane is released in the waste sector is from the disposal of solid waste in open dumpsites and landfills in India. A major portion of MSW is biodegradable or organic which, when it breaks down in the absence of oxygen, generates methane. As of 2020, around 80%-90% of India's MSW ends up in open dumpsites making open dumping still prevalent as a practice in India.[93] The Ghazipur landfill in Delhi alone emits an estimated leaking 156 tonnes per hour—that's like pollution from 24 million cars running at once.[94] Anerobic decomposition of organic waste happens when it is mixed with other components of unsegregated waste ending up in landfills. Only ~20% of Indian households segregate waste at source, leading to mixed waste streams and higher methane potential.[95]

Waste-based Methane Hotspots in India

Various sources have detected a plethora of waste-based methane plumes (localized pockets of high methane concentration arising from specific sources) in India:

Figure 24: Satellite-derived waste methane plumes over India (***Source:*** *Carbon Mapper*)

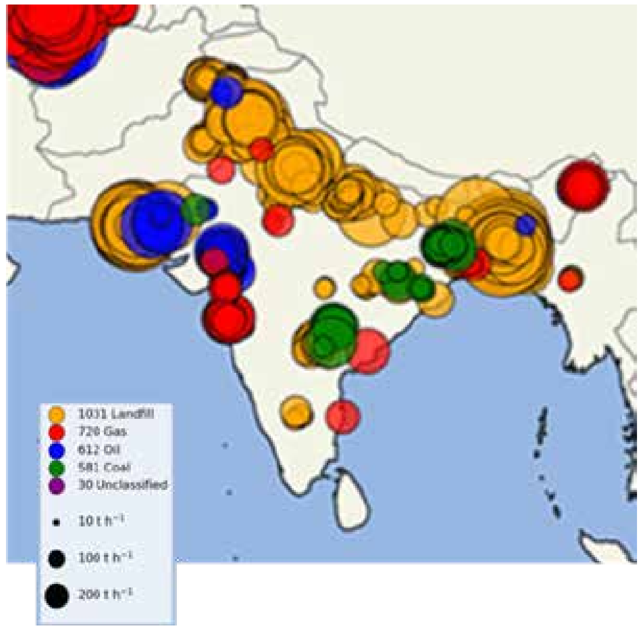


Figure 25: *Satellite-derived waste methane plumes over India* (***Source:*** *Copernicus Satellite)*

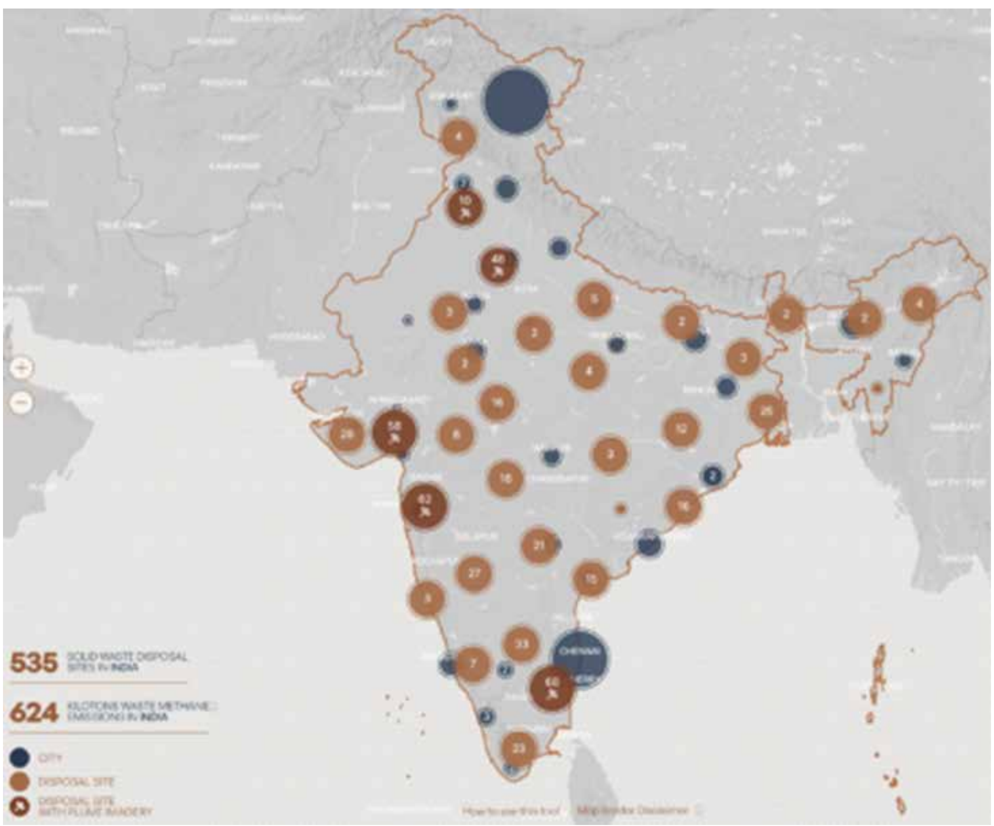


Figure 26: *Satellite-derived waste methane plumes over India* (***Source:*** *WasteMa)*

All of these maps are generated based on modelling and estimation techniques applied to satellite monitoring data, and therefore display similar emission hotspots. For the purposes of this study, the following methane emission hotspots have been identified over India.

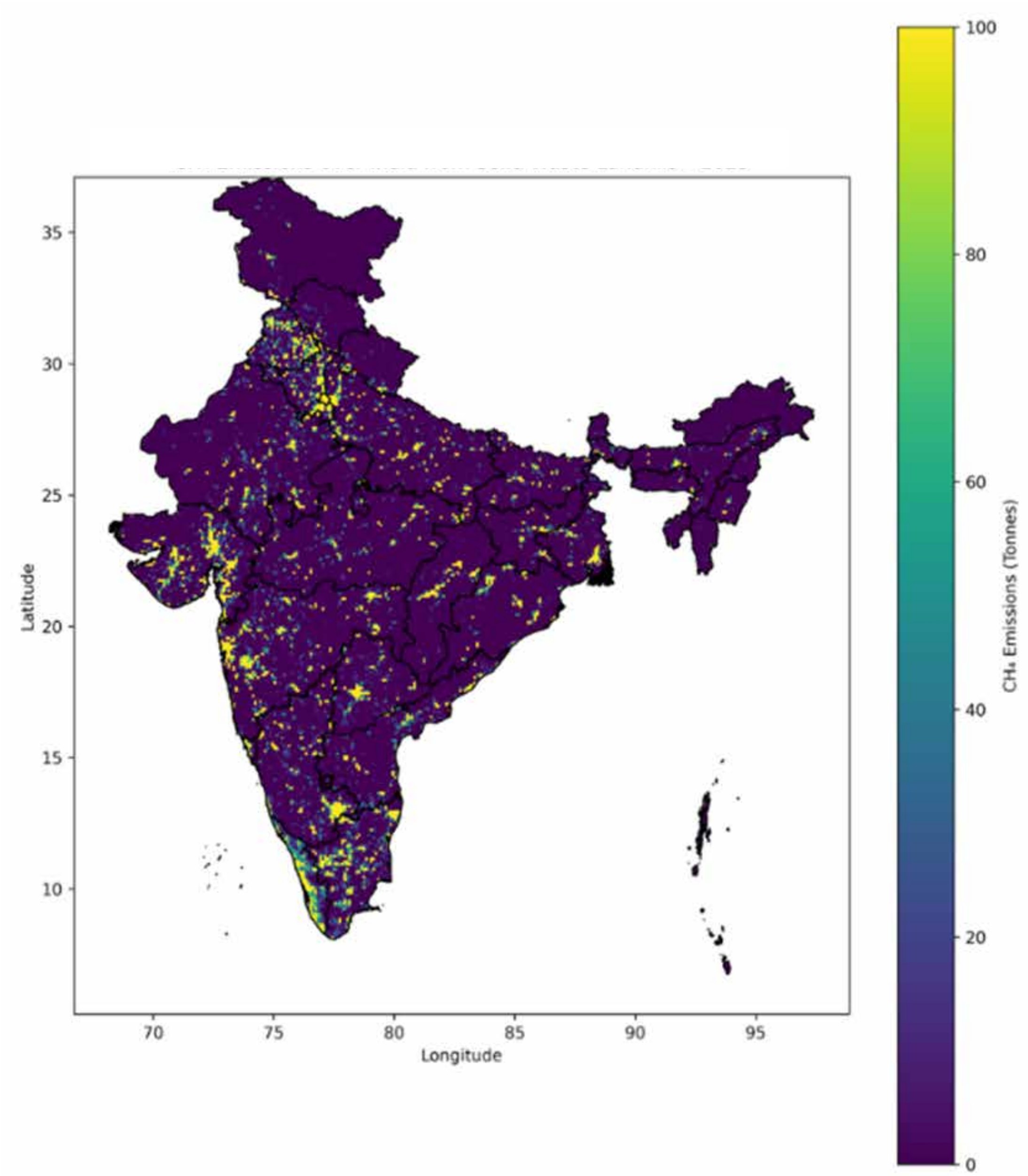


Figure 27: Methane emissions over India from solid waste landfills, 2023 (Internal Modelling and Estimation by Report Authors)

Methodology for Estimation:

The analysis draws on the EDGAR v8.1 dataset , which provides annual sector-wise GHG emission estimates at a high spatial resolution for all countries. The focus is placed on methane (CH_4) emissions from the solid waste landfill sector in India over the period 1970–2023. From this time series, emissions for the year 2023 were extracted and mapped to visualize the most recent spatial distribution of landfill-related CH_4 across the country. With a resolution of ~0.1° × 0.1°, the dataset enables the identification of detailed sub-national emission patterns, offering insights into both localized hotspots and broader regional trends.

This 2023 snapshot helps identify current high-emission zones and serves as a baseline for monitoring the effectiveness of future mitigation efforts. The resulting map reveals that methane emissions are concentrated around major urban centers including Delhi, Mumbai, Bengaluru, Chennai, and Hyderabad. These hotspots reflect the larger volume of municipal solid waste generated in densely populated cities, which, when landfilled, leads to anaerobic decomposition and methane release. Emissions are relatively lower in sparsely populated regions such as the Himalayan belt, central India, and the northeast, indicating a clear link between waste generation and urbanization. From existing and known knowledge of key large dumpsites in India, the following hotspot identification has been done on the map:

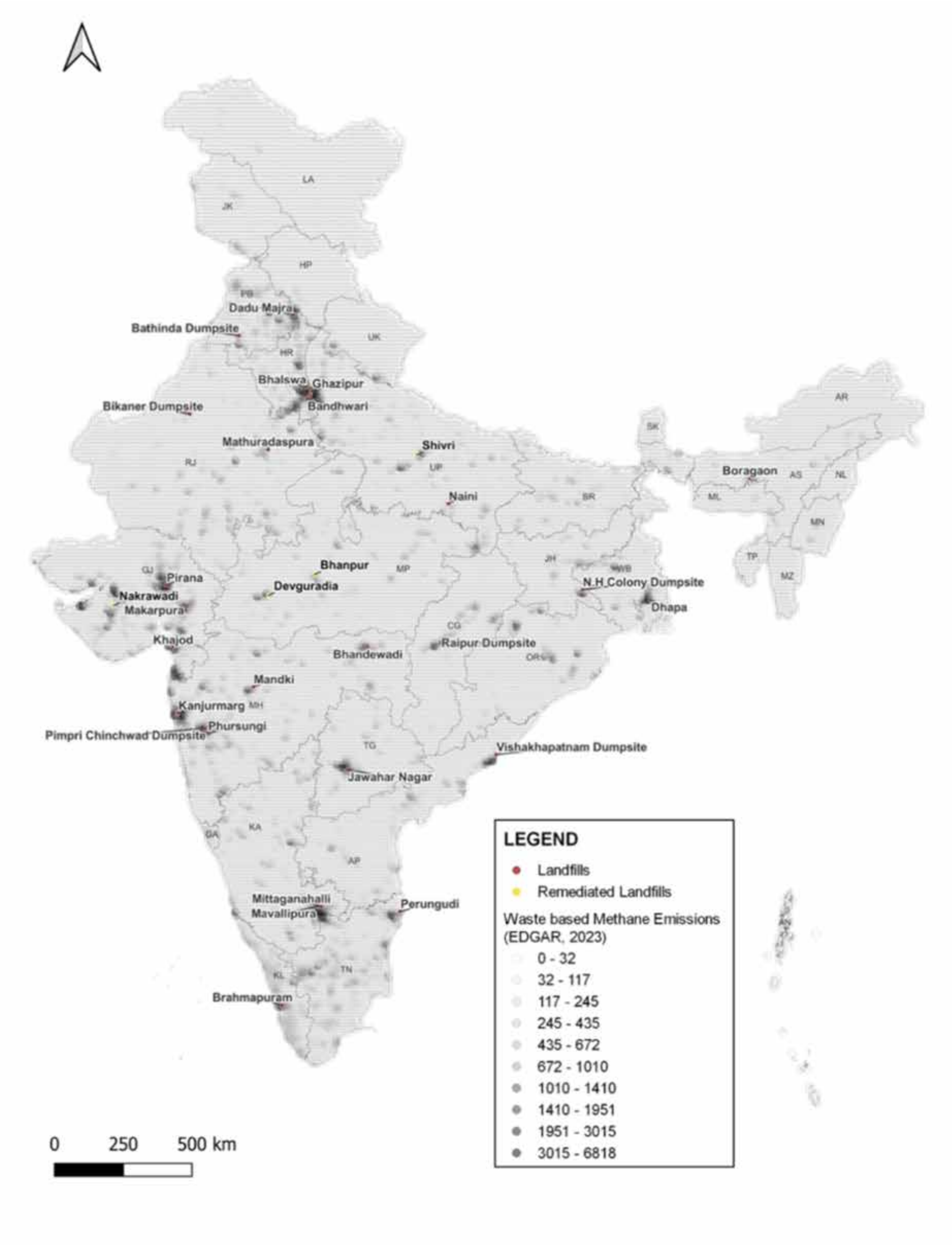


Figure 28: Identified dumpsites and landfills mapped on waste methane plumes (Internal Modelling and Estimation by Report Authors)

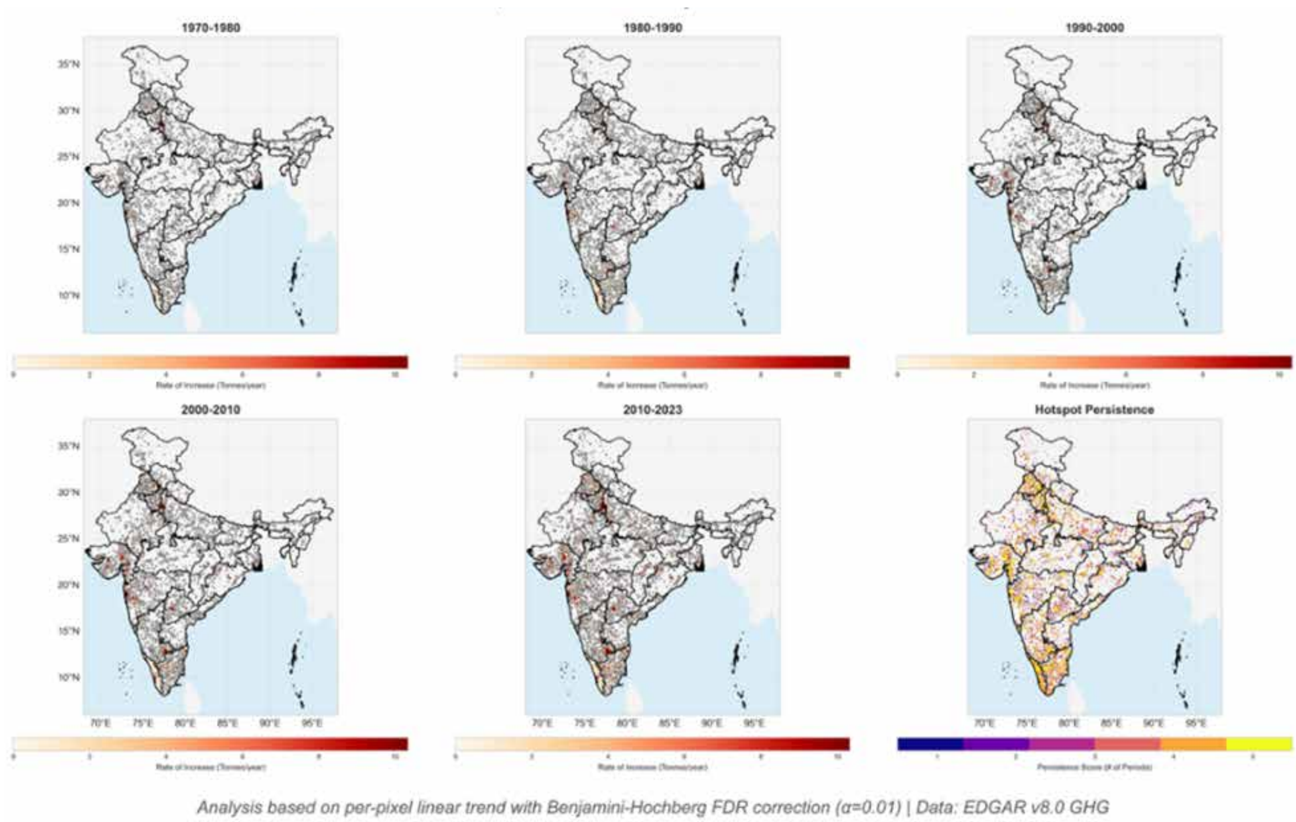


Figure 29: Decadal evolution of landfill methane emission hotspots in India, 1970 to 2023

Methodology: Using the same EDGAR v8.1 dataset, a per-pixel linear trend analysis was conducted across five time periods: 1970–1980, 1980–1990, 1990–2000, 2000–2010, and 2010–2023. This statistical assessment identified locations where methane (CH_4) emissions exhibited significant increases over time, with the linear regression slope serving as the trend metric. To enhance robustness, the analysis incorporated the Benjamini–Hochberg False Discovery Rate (FDR) correction at $\alpha = 0.01$, thereby filtering out noise and retaining only statistically significant hotspots of emission growth at the 99% confidence interval.

The figure presents five decadal maps (1970–1980, 1980–1990, 1990–2000, 2000–2010, and 2010–2023) showing the spatial evolution of methane (CH_4) emissions from landfills in India, plus a sixth panel capturing "hotspot persistence"—places where increasing trends recur across multiple decades. In early periods hotspots are sparse, but from the 1990s onward they expand markedly, first around major metros (Delhi, Mumbai, Chennai, Hyderabad, Bengaluru, Kolkata) and increasingly into Tier-II and peri-urban belts, indicating that landfill pressures have diffused beyond megacities. The persistence map outlines entrenched emission zones across western India, the Indo-Gangetic plains, and parts of the south, underscoring structural, long-standing waste-management gaps. At the same time, emergence is not uniform: different regions peak in different decades, reflecting local trajectories of population growth, urban sprawl, and waste generation—for example, southern Gujarat shows pronounced growth only after the 1990s, while many other regions remain comparatively sparse in 1990–2000. Overall, the panels illustrate both widening spread and deepening persistence of landfill CH_4, pinpointing critical zones for targeted mitigation.

2. Wastewater Treatment and Discharge

Another source of methane generation in the waste sector is wastewater. Both domestic and industrial wastewater contribute substantially to methane emissions, especially where treatment is inadequate. Methane is produced during the decomposition of organic matter in wastewater. This can occur in both wastewater treatment plants and after wastewater is discharged into the environment. With a share of 32.8% in 2018, industrial wastewater treatment and discharge was the second largest contributor to the total waste sector GHG emissions in India.

3. Open Burning

Methane emissions from open burning primarily result from incomplete combustion of organic materials such as food scraps, paper, textiles, and yard waste. When waste is burned in open air, the combustion conditions are suboptimal temperatures are often too low, and there is insufficient oxygen. This prevents the full conversion of carbon in the waste to carbon dioxide, resulting in the formation and release of methane and other products of incomplete combustion.

Scale of the problem

India is among the world's largest generators of MSW, producing over 170,000 tonnes per day.[96] The organic fraction of Indian MSW is **40–60%,** much higher than many developed countries, making methane generation from waste particularly significant.[97]

As of 2022, the waste sector accounts for 14.6% of total national methane emissions.[98] The Global Methane Initiative[99] predicts India's waste sector to contribute over 90 million tons of CO_2e in methane emissions from the waste sector in India by 2050. The figures below showcase the trajectory of methane emissions, divided by sub-sector, from waste in India.

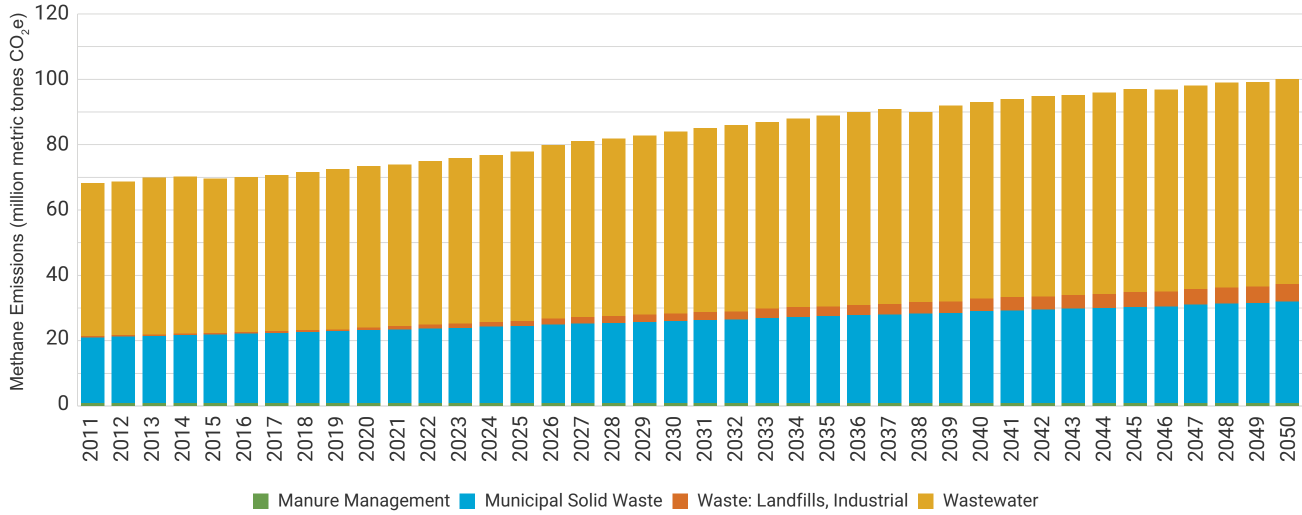


Figure 30: Projected trajectory of methane emissions from the waste sector in India, 2011 to 2050 (***Source:*** Global Methane Initiative)

Landfills emitted 1.6 billion tonnes of CO_2e in 2016, projected to reach 2.6 billion tonnes by 2050.[100] This indicates the need to immediately focus on either avoiding or capturing methane emissions from landfills. For India, the landfill methane emissions are estimated at 1.25–1.68 Tg per year. There exist multiple ways to quantify and monitor methane being released from landfills in India, but these are still untapped in India or if used are still dispersed in different parts rather than uniform. Upcoming sections delve into quantification and monitoring of methane in greater detail.

The Pollutant-Resource Paradox

Thus far, the discussion has underscored the risks posed by methane; it is equally important to recognize its potential role as part of the solution. Methane is both a climate threat and a resource opportunity.

As a GHG, methane contributes significantly to global warming while also exacerbating local air pollution and public health challenges. It plays a role in the formation of tropospheric ozone (O_3), a harmful air pollutant and short-lived climate forcer, exposure to which is responsible for an estimated one million premature deaths annually worldwide.

At the same time, methane is the principal component of biogas, and when captured effectively, it can be harnessed as a renewable energy source. Utilized either directly for power generation or upgraded into Bio-CNG for vehicular fuel, methane can reduce fossil fuel dependence and align with India's energy security and circular economy objectives.

The table below provides an overview of the potential strategies available for addressing methane in India. Subsequent sections in Chapter 3 and 4 examine each of these approaches in greater detail, assessing their feasibility, effectiveness, and limitations.

Table 18: Strategies and interventions for reducing methane emissions from the waste sector

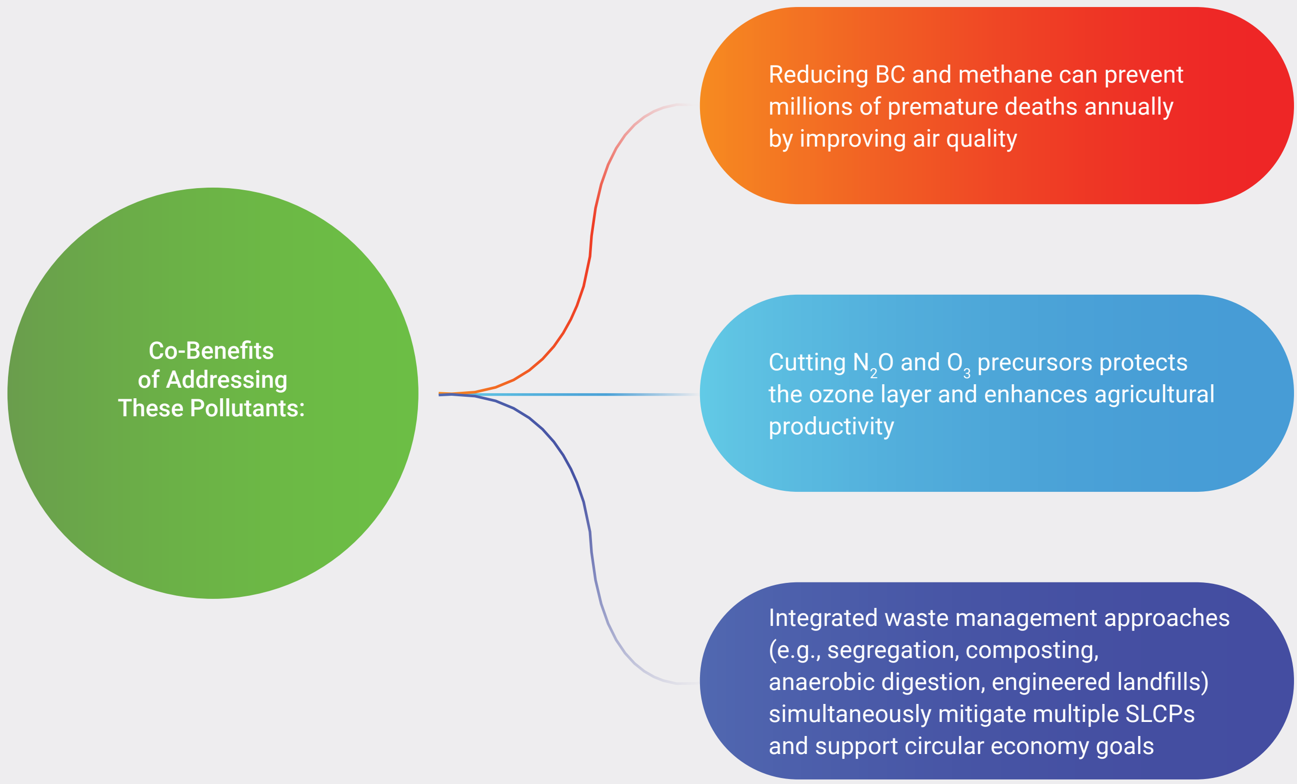
Strategy/Intervention	Key Actions & Technologies	Impact/Benefits	Example/Scale
Source Segregation & Decentralized Processing	– Scale up source segregation – Promote decentralized composting & biogas plants	– Reduces landfill methane drastically – Diverts up to 50% of MSW from landfills	Indore, Ambikapur (high segregation rates)
Engineered Landfills & Methane Capture	– Transition to sanitary landfills with gas capture – Use landfill gas for power generation	– Reduces methane emissions by 70–90% – Generates renewable electricity	Chandigarh landfill (0.27–0.77 MW potential)
Anaerobic Digestion & Biogas	– Deploy AD for segregated organic waste – Expand city-scale biogas initiatives	– Biogas potential: 5,167–14,355 MW nationwide – Proven urban/rural technology	Pune, Nashik (successful city-scale biogas)
Material Recovery Facilities (MRFs) & Recycling	– Establish/upgrade MRFs to recover recyclables from mixed waste	– Recovers >30% recyclables – Further reduces landfill and methane potential	Various urban MRFs
Data, Monitoring, & Policy	– Strengthen emissions monitoring (only 10% ULBs robust) – Enforce SWM Rules, incentivize valorization	– Enables targeted interventions - Supports compliance and innovation	CSE, 2022; SWM Rules, 2026
Co-Benefits & Circular Economy	– Improve air quality, public health – Unlock economic opportunity ($15B/year, green jobs) – Support NDCs/SDGs	– Lowers disease risk – Supports 1.5–4 million informal workers – Aligns with climate goals	Circular economy, public health, climate leadership targets

2.2.2.2 Other Non-CO_2 Emissions from Waste Sector in India

Apart from methane, the waste sector is also a significant source of other SLCPs, including black carbon (BC), nitrous oxide (N_2O), and tropospheric ozone (O_3)-either directly or through secondary processes. These pollutants contribute to climate change, air pollution, and public health risks. The table below summarizes their main sources, impacts, and effective control strategies within the waste sector.

Table 19: Other Non-CO_2 Emissions from Waste Sector in India

Pollutant	Sources in Waste Sector	Climate & Environmental Impact	Health & Economic Impact	Mitigation Strategies
Black Carbon (BC)	– Open burning of municipal solid waste – Incomplete combustion in waste incineration	– Extremely high global warming potential (460–1,500 times CO_2 over 20 years) – Accelerates ice/snow melt by darkening surfaces	– Major component of $PM_{2.5}$ pollution causing respiratory and cardiovascular diseases – Linked to millions of premature deaths annually	– Ban open burning – Improve combustion efficiency – Install filters in incinerators – Promote waste segregation to reduce combustibles
Nitrous Oxide (N_2O)	– Wastewater treatment (biological nitrogen removal) – Incineration of waste and sewage sludge	– ~273–300 times CO_2 global warming potential over 100 years – Long atmospheric lifetime (~114 years) – Ozone-depleting substance	– Indirectly affects health via climate change impacts – Contributes to stratospheric ozone layer depletion	– Optimize wastewater treatment operations – Advanced process controls – Catalytic destruction technologies
Tropospheric Ozone (O_3)	– Formed by photochemical reactions between NO_x and VOCs emitted from waste operations and decomposing organic waste	– Potent GHG contributing ~0.4°C to global warming – Secondary pollutant, not directly emitted	– Damages respiratory system causing asthma and COPD – Reduces crop yields significantly (wheat, rice)	– Control NOx and VOC emissions from waste facilities – Promote composting and biogas to reduce organic waste VOCs



2.3 Methods for Estimating Methane Emissions

To reduce the total CH_4 emission value, a strong policy narrative – that can draw linkages and emphasizes on the relevance of methane mitigation in waste management - is required in India. Quantifying methane emissions is foundational to form this narrative. Accurate measurement and monitoring of methane releases can pave the path for informed decision-making and effective action, thereby spearheading environmental stewardship, regulatory compliance, and economic opportunity,

In India, due to inadequate data availability, a large amount of uncertainty related to MSW management and emissions has been observed, which makes it difficult to estimate the accurate value for the landfill GHG emission potential. The International Panel on Climate Change has established a method for the estimation of GHGs emitted from landfills that has been widely used by researchers. Studies have been conducted using different methods, including the stoichiometric method, default method (DM), FOD, MTM, in situ closed chamber methods, and the Land GEM.

2.3.1 Overview of Estimation Methodologies

The following table provides an overview of the key tools and technologies available for estimating methane emissions from the waste sector, outlining their descriptions, advantages, limitations, suitability in the Indian context, and real-world application examples.

Table 20: Overview of methane estimation tools and technologies

Tool/Technology	Description	Advantages	Limitations	Suitability	Application Example
LandGEM Model	Automated USEPA model for estimating landfill gas emissions; uses default or site-specific inputs.	▪ Free, globally used ▪ Site-specific estimates ▪ Easy to implement	▪ Needs accurate input data ▪ Not real-time ▪ Defaults may misestimate local conditions	▪ Large urban landfills ▪ Moderate data availability ▪ Good for baseline estimates ▪ Low-cost	Applied at Kanuru landfill, Vijayawada to estimate methane & energy potential[101]
SWEET	Excel-based tool (Global Methane Initiative/CCAC) to quantify methane, black carbon, and other emissions.	▪ Adaptable to Indian practices ▪ User-friendly ▪ Scenario planning	▪ Relies on data quality ▪ Waste sector only ▪ Not real-time	▪ City-level inventories ▪ Scenario planning ▪ Works with limited data	Applied for Waste Sector emissions analysis in Pathways to Net Zero in Punjab: The Critical Role of Non-CO_2 Pollutants[102]
Surface Flux Chambers	Chambers placed on landfill surfaces to directly measure methane flux.	▪ Direct measurements ▪ Good for research ▪ Model calibration	▪ Limited coverage ▪ Labor-intensive ▪ Not continuous	▪ Small-scale studies ▪ Research & validation ▪ Urban/rural sites	Deployed in north-east India landfill to measure seasonal flux[103]
Remote Sensing	Satellite/aircraft-based tools detecting methane plumes over large areas.	▪ Covers vast areas ▪ Detects super-emitters ▪ Independent verification	▪ High cost ▪ Needs expertise ▪ Limited temporal coverage	▪ National/metro scale ▪ Good for prioritizing sites	Satellites identified Delhi landfills as methane super-emitters[104]
Handheld Instruments	Portable detectors for on-site methane leak detection.	▪ Easy to use ▪ Low cost ▪ Immediate readings	▪ Limited coverage ▪ Snapshot data only	▪ Quick surveys ▪ Leak detection ▪ O&M checks	Used in walkover landfill leak surveys globally[105]
Drone Surveys	Drones with methane sensors for landfill plume mapping.	▪ Covers large areas ▪ Identifies hotspots ▪ High-resolution mapping	▪ High cost ▪ Needs skilled operators ▪ Complex data processing	▪ Large landfills ▪ Identifies hotspots ▪ Moderate cost vs satellites	Orange County 'Smart Landfill' program[106]
IPCC Guidelines	Tiered methodologies for estimating methane from waste, using default or detailed data.	▪ Comprehensive ▪ Globally recognized ▪ Provides defaults	▪ Generalized assumptions ▪ Coarse for site-level ▪ Data intensive at higher tiers	▪ National/state inventories ▪ Default values useful ▪ Consistent reporting	Chandigarh landfill methane emission estimation via FOD[107]
Emission Factor Database	Uses established factors (e.g. kg CH_4/ton waste) for simple emission estimates.	▪ Quick estimates ▪ Minimal data needed ▪ Useful for screening	▪ High uncertainty ▪ Not site-specific ▪ Depends on factors	▪ Small towns/ districts ▪ Low data availability ▪ Preliminary assessments	Such factors exist for energy related emissions – published by IEA[108]

Tool/Technology	Description	Advantages	Limitations	Suitability	Application Example
LCA	Lifecycle method assessing emissions (including methane) across waste stages.	▪ Holistic ▪ Identifies trade-offs ▪ Supports strategy	▪ Data-intensive ▪ Complex methods ▪ Not for daily ops	▪ Policy/strategy planning ▪ State/city projects ▪ Compares management options	Visakhapatnam LCA: digestion + semi-aerobic landfill cut emissions 90%[109]
Gas Chromatography	Lab technique for precise methane concentration measurement in samples.	▪ High accuracy ▪ Gas speciation ▪ Reference standard	▪ Needs lab ▪ Sample transport ▪ Not for large-scale	▪ Research/ validation ▪ Calibration of other tools	Used for validation of models in landfill gas studies[110]
Mobile Methane Systems	Vehicle-mounted analyzers measuring methane plumes in real time.	▪ Real-time plume tracking ▪ Large area coverage ▪ Effective verification	▪ High cost ▪ Needs experts ▪ Source pinpointing limited	▪ State/national surveys ▪ Audits & verification	Used in California to survey landfill plumes[111]
Inventory Tools	Frameworks/ software compiling waste methane data for inventories (e.g., ClearPath, SIT).	▪ Comprehensive analysis ▪ Supports policy ▪ Standardized reporting	▪ Data intensive ▪ Needs strong institutions ▪ Input quality critical	▪ National/city inventories ▪ Global Methane Pledge reporting	CCAC-supported waste methane inventory in Nigeria.[112]

2.3.2 Parameters: Methane Generation Potential, Recovery, Oxidation

The estimation of methane emissions from landfills requires careful consideration of key parameters that influence the amount of methane generated, recovered, oxidized, and ultimately emitted to the atmosphere. These parameters are embedded in most recognized estimation models, including those recommended by the IPCC and implemented in tools such as the LandGEM model and the Solid Waste Emissions Estimation Tool (SWEET).

The methane generation potential (L0) represents the maximum amount of methane that can be generated per tonne of waste under ideal anaerobic conditions. It is dependent on the organic fraction of MSW, particularly biodegradable components like food, paper, and garden waste. According to IPCC 2006 guidelines, a default value of L0 = 100-200 m3 CH4 /tonne of waste is recommended for developing countries. As per MCGM analysis (US EPA, 2006), the methane generation potential (Lo) of the landfill site of Mumbai was 68 m^3 /Mg (cubic metre per mega gram or metric ton)[113]. In another study, the value of Lo was taken as 130 m^3/tonne of waste generated.[114]

Methane recovery potential refers to the portion of methane generated within a landfill that can be practically captured through a landfill gas (LFG) collection system. This captured gas may be flared or used for energy production, reducing overall emissions. The recovery efficiency depends on landfill design, operation, and gas collection infrastructure. According to one estimate, only 20–25% of landfill gases can be recovered, while the rest of the gases escape into the atmosphere.[115] If properly designed landfills are established, 30–60% of the gases can be utilized from these controlled landfills.[116] These recovered landfill gases can be used as a direct source of energy and for power generation or can be upgraded into vehicle fuel.[117]

The oxidation factor accounts for the fraction of methane oxidized into carbon dioxide as it passes through the landfill cover soil. Methane oxidation occurs naturally due to microbial activity in the layers. IPCC recommends a default oxidation factor of 0.1 (10%) for unmanaged landfills and up to 0.2 (20%) for engineered landfills with well-maintained covers. In India's context, most landfills are unmanaged, so a lower oxidation factor (~0.05 to 0.1) is generally applied.[118]

2.4 Data Availability and Monitoring Challenges

2.4.1 Inconsistencies in Regulatory Data

Reliable and harmonized datasets are critical for shaping evidence-based policies in waste management. Without consistent and comparable information, policymakers face significant challenges in assessing the scale of the problem, designing effective interventions, and tracking progress over time. Discrepancies in data not only undermine the credibility of reporting frameworks but can also lead to misallocation of resources and ineffective planning at both state and national levels. In the Indian context, where solid waste management is a complex and multi-layered challenge involving multiple institutions, alignment of data sources becomes particularly important.

In this regard, the discrepancies noted in *Section 2.1.2* between Central Pollution Control Board's (CPCB) annual report and the SBM Urban Dashboard - two of the most authoritative sources of information on waste management in India - highlights the challenge of reconciling institutional data. This also becomes a persistent challenge in assessing methane emissions from India's waste sector from the bottom-up level.

A likely explanation of divergence in data may be the different methodologies adopted by the two platforms. CPCB data is primarily compiled through inputs from State Pollution Control Boards, while the SBM Urban Dashboard draws directly from municipal corporations. Differences in reporting authorities, data collection mechanisms, and definitions of what constitutes an "operational dumpsite" may all contribute to the observed gap.

Accurate and harmonized data on dumpsites is essential for the development of effective waste management strategies. It enables policymakers to identify priority areas for intervention, evaluate the success of ongoing programs, and ensure accountability in the implementation of national missions such as Swachh Bharat. Addressing discrepancies between institutional datasets will therefore be a critical step towards strengthening waste governance and ensuring sustainable management practices across India.

For the purposes of the upcoming analysis in Chapter 4, the report adopts the CPCB inventory as the working baseline. This discrepancy does not materially affect the methane emission projections presented in this report. Methane generation estimates are primarily driven by waste volume, organic waste fraction, and decomposition dynamics, rather than the absolute number of dumpsites. Consequently, the analysis focuses on **aggregate waste quantities and treatment pathways,** using dumpsite inventories mainly as spatial indicators of legacy waste distribution.

These inconsistencies highlight the broader need for **integrated waste data systems and standardized reporting protocols** across national platforms to support accurate monitoring, reporting, and verification (MRV) of waste management sector. With the advent of Solid Waste Management Rules 2026[119], there is a strong push on digitized reporting across the waste value chain which should result in fixing this gap as well, expecially through the dedicated Dumpsite Remediation Acceleration Program (DRAP) progress dashboard.[120]

2.4.2 Lack of Real-Time Monitoring at Landfills

Real-time monitoring of methane at landfills is critical for effective waste management and climate action. Methane's highly flammable nature has contributed to recurring surface fires and subsurface explosions in Indian landfills and dumpsites. Real-time monitoring enables early detection of methane build-up, allowing operators to intervene before hazardous conditions develop. Continuous monitoring provides accurate data on emissions trends, strengthening GHG inventories and supporting mitigation strategies aligned with India's commitments under global frameworks. These considerations highlight the need to transition from periodic emission estimates to continuous, on-site methane monitoring systems at Indian landfills.

Moreover, continuous monitoring enables the timely capture of landfill gas (LFG) for energy recovery, ensuring that methane is not only prevented from escaping into the atmosphere but is also harnessed as a renewable resource to generate electricity or fuel vehicles. Methane emissions from landfills represent a substantial share of India's GHG profile. Peer-reviewed studies estimate that India's landfill methane emissions are in the range of 1.25–1.68 Tg (1,250–1,680 Gg) per year, corresponding to 16–20 million tonnes CO_2-equivalent annually, and are projected to increase further as urbanization accelerates.[121] The high organic content of Indian MSW (often exceeding 50%) and climatic factors result in rapid landfill gas generation, with peak methane emissions occurring shortly after landfill closure.[122] Despite this, almost none of the methane emitted from Indian landfills is currently captured or utilized as a renewable energy source.[124] The Solid Waste Management Rules, 2026, require larger landfills to install landfill gas capture and utilization systems[125], but implementation is limited by technical and financial barriers.[126]

Effective landfill management, including engineered landfill construction, phased closure, and the installation of LFG capture systems, can reduce methane emissions by 60–90%, depending on site-specific conditions and operational efficiency.[127] For example, research on the Chandigarh landfill demonstrates that with proper gas capture, methane emissions could be substantially reduced, while also enabling energy recovery of 0.27–0.77 MW from just one site.[128] Extrapolated nationally, India's landfills could generate 5,167–14,355 MW of renewable energy, offering a dual opportunity for GHG mitigation and sustainable power generation.[129] These measures directly support India's commitments under the Paris Agreement and its NDCs.[130] Additionally, the implementation of landfill gas capture projects opens avenues for carbon finance and the generation of carbon credits, incentivizing further investment in sustainable landfill management.

2.4.3 Apparent Decoupling: What the Data May Be Hiding

Decoupling refers to the separation of economic growth from environmental degradation, typically measured through GHG emissions. In practice, it can be relative, where emissions continue to rise but at a slower pace than GDP growth, or absolute, where the economy grows while total emissions decline.[123]

An analysis of India's waste sector indicates an emerging trend of decoupling between GHG emissions and both economic growth and waste generation between 2014 and 2020. During this period, waste sector GHG emissions declined by 3.31% (from 78,227 Gg CO_2e to 75,641 Gg CO_2e), even as per capita waste generation rose and the national GDP expanded by 38.23%. Relative Decoupling Indices (RDI) further illustrate this:

However, these trends must be interpreted with caution. Current estimates are constrained by significant data gaps, particularly in rural India, where 65% of the population resides[131]. Waste from informal settlements, peri-urban areas, and tourist destinations is often excluded from official inventories, despite widespread practices of open dumping and burning that release large volumes of methane and other GHGs. **Without robust, comprehensive data collection that captures these overlooked sources, the apparent progress in decoupling may be overstated.** Strengthening monitoring and reporting systems, especially in rural and informal contexts, is therefore critical to ensure that India's waste-sector emissions are fully and accurately represented.

The activity-based RDI of -0.83 signifies strong absolute decoupling between emissions and waste generation, indicating improved operational efficiency in waste management.

The GDP-based RDI of -0.086 shows a weaker, but still absolute, decoupling of emissions from economic growth, suggesting early success in containing emissions despite economic expansion.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CHAPTER 3:

ANALYSIS OF THE LANDFILL MANAGEMENT ECOSYSTEM IN INDIA

Landfill management in India is shaped by a complex ecosystem of policies, institutions, technologies, and practices that often operate in silos. While the following sections discuss key components ranging from collection and transportation to landfill design, remediation, and regulatory oversight—the central challenge lies in their fragmented implementation. Without a cohesive strategy that links these elements, waste continues to escape systematic handling, leading to persistent environmental and public health risks. This chapter therefore examines the ecosystem in detail, with an emphasis on how integrated approaches can ensure landfills move from being uncontrolled dumpsites to scientifically managed facilities.

3.1 Infrastructure: Gaps and Interventions

India's solid waste management system continues to face major structural deficiencies, most visibly in the absence of engineered solutions such as sanitary landfills with impermeable liners, leachate collection systems, landfill gas capture, and scientifically designed transfer stations. Instead, open dumping remains the norm, resulting in leachate percolation, uncontrolled methane emissions, and frequent fires. These infrastructural gaps translate directly into groundwater contamination, air pollution, and public health risks for communities living near dumpsites. Addressing them requires systematic investment in engineered facilities alongside improved collection, segregation, and processing systems, backed by strong regulatory and policy enforcement to ensure waste is treated and only inerts are sent to a sanitary landfills.

The Road Ahead: From Gaps to Groundwork While these infrastructural deficits remain real today, India's regulatory response to them has never been stronger. The fast-tracked, leadership-driven remediation model under DRAP, SBM-U 2.0's "Lakshya Zero Dumpsites" push, and the SWM Rules, 2026's binding provisions on landfill design, LFG capture, and time-bound remediation together mark a genuine shift — from prescriptive intent to structured, funded execution. If sustained at this pace, this convergence of political will, financing, and regulatory backing offers the clearest pathway yet to closing India's long-standing infrastructure gap.

3.1.1 Infrastructure Gaps

1. Unscientific Landfill Infrastructure:

Prevalence of Open Dumpsites: A primary infrastructural challenge is India's continued reliance on open dumpsites, which lack the design and operational controls of engineered sanitary landfills. CPCB's 2022–23 Annual Report records 2,474 active dumpsites nationally, of which only 421 have been reclaimed or converted to sanitary landfills.[132,133] This backlog is now directly targeted by the Dumpsite Remediation Accelerator Programme (DRAP), launched in November 2025, and the SWM Rules, 2026's time-bound legacy dumpsite remediation mandate, though dumpsites outside DRAP's 214 priority sites still lack an equivalent funded pathway.

Absence of Impermeable Liners: Open dumps universally lack basal liner systems and engineered leachate collection or treatment infrastructure, allowing contaminated leachate to infiltrate soil and groundwater largely unchecked. Nitrate levels in borehole water near Delhi's Ghazipur landfill have been found to exceed 75 mg/L, well above the BIS limit of 45 mg/L, directly attributable to the lack of containment. The SWM Rules, 2026 strengthen landfill design and leachate management standards, but retrofitting this infrastructure into thousands of existing open dumps remains a capital-intensive, multi-year task.

Uncontrolled Landfill Gas (LFG) Emissions: Anaerobic decomposition in unscientific dumps generates substantial methane. The SWM Rules, 2026 now introduce an explicit LFG capture mandate at sanitary landfills, alongside the existing 25% lower-explosive-limit cap, but the large stock of open dumpsites still lacks active LFG collection systems, leaving emissions, climate impact, and explosion hazards largely uncontrolled pending DRAP-led remediation.

Lack of Daily and Final Cover: Daily soil covering and multi-layered final capping remain rare in open dumps, worsening odour, pest proliferation, fire risk, and rainwater infiltration. DRAP's site-level micro-action plans are intended to close this gap as dumpsites are bio-mined and reclaimed, but it persists at sites not yet under structured remediation

2. Inadequate Waste Processing and Ancillary Infrastructure:

Limited Scientific Treatment Capacity: As per CPCB's 2022–23 Annual Report, national collection efficiency stands at approximately 96%, while only about 61% of total waste generated is processed or treated — up from 36.46% in 2017–18 — and roughly 22% is landfilled, leaving a 17% gap. The SWM Rules, 2026 push to close this through the Extended Bulk Waste Generator Responsibility (EBWGR) framework and a phased RDF substitution mandate rising from 6% to 15% over six years.

Insufficient Material Recovery Facilities (MRFs): A severe deficit in well-equipped MRFs across ULBs continues to hinder efficient segregation and recovery of dry recyclables (plastics, paper, metals, glass), leading to the loss of valuable resources to landfills and dumpsites. The SWM Rules, 2026's four-stream segregation mandate raises the bar further, since most existing MRFs were designed for only two or three streams.

Scarcity of Organic Waste Processing Facilities: Given the high organic content (typically 40–60%) in Indian MSW, there remains an acute shortage of composting and anaerobic digestion facilities to convert biodegradable waste into compost or biogas and reduce landfill dependency. This remains largely unaddressed directly by the 2026 Rules, though EBWGR and DRAP's fresh-waste prevention mandate create indirect pressure to expand capacity.

Challenges in Waste-to-Energy (WtE) Plant Operation: India currently has 22 WtE plants (including biogas plants) operational, generating approximately 207 MW. Optimal operation remains compromised by the low calorific value and high moisture content of MSW due to inadequate source segregation, often necessitating supplementary fuel and impacting viability, alongside continuing emission-control concerns for pollutants like dioxins and furans. The SWM Rules, 2026 aim to reposition WtE as a residual pathway rather than a primary one, but this shift is only beginning to reach plant-level practice.

Lack of Transfer Stations: An insufficient number of strategically located waste transfer stations continues to drive inefficiencies in waste logistics, increasing transportation costs and GHG emissions as waste is hauled directly over long distances to dumpsites. This gap remains unaddressed by the SWM Rules, 2026.

Rigorous enforcement of source segregation at the household and commercial levels (at least into wet, dry, and domestic hazardous waste) is fundamental as outlined in the SWM Rules, 2016.[134] This enables more efficient subsequent processing through:

- **Decentralized Composting/Biomethanation Units:** Establishing smaller-scale facilities for organic waste processing at community or ward levels to reduce transportation burdens and generate local resources. The Ministry of New and Renewable Energy (MNRE)'s National Bio-Energy Programme and GOBARdhan Scheme provide financial and technical support for biogas and bio-CNG plants from organic waste.[135]
- **Well-Equipped Material Recovery Facilities (MRFs)**: Developing state-of-the-art MRFs at strategic points to maximize the recovery of high-value recyclables from the dry waste stream, improving their market value and reducing landfill load. Agra, for example, has established four MRFs with a combined capacity of 405 TPD.[136]

Optimizing Waste-to-Energy (WtE) Operations:

- **Pre-processing of Waste:** Implementing pre-processing technologies (e.g., shredding, drying, magnetic separation) to improve the calorific value and homogeneity of waste fed into WtE plants, thereby enhancing combustion efficiency and reducing auxiliary fuel requirements.
- **Advanced Emission Control and Monitoring:** Mandating and ensuring the installation of advanced flue gas treatment systems and continuous emission monitoring systems in all WtE plants comply with stringent environmental standards.

Integrated Waste Processing Parks:

Promoting the development of comprehensive waste processing parks that integrate multiple treatment technologies (e.g., composting, MRFs, WtE, construction & demolition waste recycling) within a single complex to streamline operations and maximize resource recovery.

3.2 Technological Interventions for Improved Landfill Management

India's landfill management faces significant hurdles, primarily due to technological limitations and a lack of proper infrastructure. Most dumpsites in the country lack fundamental environmental controls and monitoring systems. This absence extends to crucial features like **methane gas extraction and leachate treatment,** leading to uncontrolled emissions and widespread pollution.

Given the escalating solid waste problem and limited land availability, targeted interventions – especially tech-forward innovations – are crucial. This assumes more importance when the interventions are aimed at mitigating methane emissions. This section focuses on current and emerging technologies designed to address landfill-specific issues, emphasizing methane mitigation, legacy waste remediation, and enhanced landfill management practices, assessing their relevance, feasibility, and scalability within the Indian context.

3.2.1 Bio-covers for Landfill Methane Mitigation in India

3.2.1.1 Introduction to biocovers:

Biocovers are specifically designed soil layers that are applied over landfills to minimize methane emissions. They utilize natural materials such as compost to transform methane into carbon dioxide and water. The transformation happens within the cover material. This process helps to mitigate a powerful GHG into a less detrimental one. Biocovers function by facilitating an ideal environment for methanotrophic bacteria, which are specialized microorganisms that utilize methane as their primary energy source. As methane escapes from waste materials, these bacteria metabolize through a process facilitated by the presence of oxygen from the atmosphere. This natural exchange significantly reduces the amount of methane released into the surroundings, consequently contributing to lower GHG emissions[137].

Biocovers are somewhat different from biocapping. Biocapping is a rather broad term in which landfill sites are sealed with organic substances to prevent gas escaping. It concentrates on the containment of waste materials. In contrast, biocovers facilitate methane metabolism by promoting the natural breakdown of organic materials. However, overlaps exist where biocapping of a solid waste landfill site includes microbial layers for the oxidation process[138]. Furthermore, bioremediation is a larger umbrella that embodies techniques utilized to minimize pollution by use of living organisms. The natural biological method used by organisms such as bacteria, fungi, and plants to detoxify or eliminate potentially dangerous substances from a contaminated area, like soil, water, or air. Nevertheless, bioremediation overlaps with biocovers, since both are biodegradation processes that rely on microbes for the minimization of harmful gases[139].

Bio-covers can nevertheless be implemented **as an enhanced landfill cover or final capping layer within dumpsite remediation projects.** In practical terms, this means that methane oxidation layers would need to be **integrated into landfill closure or remediation design specifications,** rather than procured as a separate technology category in municipal tenders. Recognizing this regulatory gap, future updates to national waste management guidance could provide **explicit technical standards for methane oxidation covers,** enabling urban local bodies to adopt this mitigation option more systematically.

3.2.1.2 Technology Overview & Working Mechanism

- **Design and Application Process**

  The installation of biocovers involves site preparation, laying down materials, and planting vegetation as necessary. They thickness of biocovers layber varies between 0.5 and 1.5 meters and the design focuses on creating an ideal environment for microbes. There are two functional layers in a strong design. Gas distribution occurs at the bottom layer. The topmost layer is the methane oxidation layer, which is composed of bioactive media such as mature compost. Hotspots or leachate wells supply gas passively or can be provided actively through perforated pipes buried in the distribution layer. The surface is sloped to prevent ponding and to shed water. Drainage controls protect the active layer's aerobic conditions and to avoid gas bypass[140].

- **Typical Materials Used**

  The oxidation layer typically consists of well-matured green waste compost that is stable and free of readily biodegradable organic compounds. This minimizes oxygen loss by utilizing heterotrophic microbes. For efficient gas diffusion and the development of aerobic zones, which promote methanotrophic activity, the air-filled permeability should be maintained at or above 14% by volume. Moreover, to balance gas flow while minimizing the possibility of preferential paths, the distribution layer has been made up of coarse granular media such as gravel[141].

- **Step-by-step Working Mechanism**

Here is a step-by-step explanation of the methane oxidation process in biocovers, with a focus on microbial roles:

1. **Methane Migration from the Waste Mass:** Methane gas is generated when biological waste decomposes in a landfill site without oxygen. This methane produced rises naturally toward the earth's surface, either passing through a gas distribution layer or penetrating directly through the soil, which distributes the gas more evenly[142].
2. **Diffusion into the Methane Oxidation Layer:** Above the waste material lies the methane oxidation layer, often composed of compost or a compost-soil mixture. In this area, subsurface methane interacts with oxygen from the atmosphere. The balance between methane flow and oxygen supply is vital to how effectively the process works[143].
3. **Helpful Microbes in Action:** This layer is host to unique microorganisms known as methanotrophs. There are two primary kinds, Type I and Type II, which flourish in somewhat different environments. These microorganisms are the "workers" that decompose methane before it is released into the atmosphere[144].
4. **Stepwise Conversion of Methane:** To initiate the process of methane conversion, microbial cells require enzymes, primarily methane monooxygenase. Methane (CH_4) is converted into methanol, then into formaldehyde, and finally into carbon dioxide (CO_2) and water. This not only eliminates methane but also supplies energy and nutrition to the bacteria[145].

5. **Final Action Stage:** A significant amount of the methane is destroyed at the top layers, where oxygen is most easily accessible; however, some activity remains below the surface if oxygen penetrates deep enough. Ensuring that the gas is uniformly distributed helps to minimize "hotspots" where methane can escape.[146]

3.2.1.3 Methane Mitigation Potential

Bio-covers are widely recognised as an effective technology for mitigating methane emissions from solid waste dumpsites. Studies have reported methane reduction efficiencies ranging from 30% to 80%, with well-designed systems achieving reductions of 70–90% or more under favourable conditions. Their performance largely depends on the choice of cover material, with compost-based bio-covers demonstrating particularly high methane oxidation potential due to their rich microbial activity. Climatic conditions also influence effectiveness, as warmer and more humid environments promote greater microbial activity and oxygen diffusion, whereas colder climates tend to reduce oxidation rates. Under typical operating conditions, bio-covers can oxidise at least 2 g CH_4/m^2/day, with significantly higher rates reported in optimally designed systems. When combined with landfill gas collection systems, bio-covers can contribute to overall methane emission reductions exceeding 90%.[147].

3.2.1.4 Cost Considerations

The cost of applying biocovers varies depending on the local accessibility of materials; for instance, locally available compost can lower both costs and transportation emissions. Additional expenses would involve setting up biofilters or biocovers, as well as ongoing maintenance costs, such as irrigating the oxidizing materials in parched regions and assessing the technology's efficiency over time. The average capital expense for a biocover is approximately $48,000 per acre[148].

3.2.1.5 GlobalCase Studies

The Fakse landfill site in Denmark is recognized as a notable example of success in biocover technology on a global level. This is a pilot project funded by the EU that utilized engineered biocovers to enhance methane oxidation in landfill soil. It showed how small modifications can significantly reduce emissions at old landfill sites. Performance levels achieved reductions of up to 30 percent in methane emissions, even with some leaks present. Improved designs in subsequent trials achieved over 90 percent efficiency in similar configurations. These results confirm that biocovers are effective and cost-efficient for managing gas emissions[149].

3.2.1.6 Current Status in India

The application of biocovers as a specific methane mitigation technology remains limited in India. Most landfill disposal initiatives carried out under the Solid Waste Management Rules 2026 and the SBM (Urban) focus on “bioremediation” or “biocapping.” In government and policy papers, these phrases are frequently used synonymously with biocovers, even though they properly refer to broader site closure and stabilization methods rather than focused microbial methane oxidation[150].

A few pilot initiatives have been undertaken to address waste management issues. For instance, the Central Pollution Control Board (CPCB) has documented projects for remediating dumpsites in Delhi, specifically at Ghazipur, Bhalswa, and Okhla. These projects involved applying stabilized waste and compost-based covers to help suppress odors and surface emissions[151]. Additionally, the National Environmental Engineering Research Institute (NEERI) has investigated cover systems for handling landfill gas in controlled environments. This study helps to focus on the effectiveness of Indian compost and soil mixtures for promoting methanotrophic activity. Furthermore, academic institutions such as the Indian Institutes of Technology (IITs) have conducted experimental studies on the potential for microbial methane oxidation using laboratory-scale biocover models utilizing local organic residues[152].

Despite ongoing initiatives, the adoption of biocovers throughout India remains in the initial stages. Some gaps exist, and several challenges hamper widespread implementation. Firstly, there is a lack of clear technical standards or guidelines that would clearly classify biocovers as a separate methane mitigation technology, different from general landfill capping. Secondly, the capacity for monitoring and verification at the municipal level is insufficient, making it difficult to document methane reduction. Additionally, the variability of seasonal climates across India, particularly the impact of heavy monsoon rains, presents operational difficulties. Lastly, a lack of awareness among municipal authorities and the inadequacy of financial incentives further discourage the implementation of large-scale deployment. Overcoming all these obstacles is crucial for integrating biocovers into India’s landfill management framework[153].

3.2.1.7 Policy & Regulatory Landscape

The Indian government has implemented key legislation and regulations regarding solid waste management. India's policy and regulatory landscape, which encompasses solid waste management and landfill sites, is comprehensive and aligns with global efforts to mitigate climate change. This section provides an overview of both national and international regulations related to reducing methane emissions from landfills.

- **Solid Waste Management Rules 2026**

  The SWM Rules, 2026, regulate landfill operations by requiring biomining and proper capping of sites to prevent pollution and protect the environment. These rules are intended to minimize methane emissions through better landfill management. However, the rules reference biological capping but do not explicitly define "biocovers" as a specific mitigation technology[154].

- **CPCB Guidelines 2019**

  The CPCB Guidelines 2019 provide a structured framework for the remediation of legacy waste landfill sites across India. These guidelines recommend biomining and bioremediation as preferred methods to restore land and materials while minimizing environmental hazards. The guidelines define systematic processes, including waste digging, segregation, and disposal of recyclables in sanitary landfills. According to the 2019 CPCB Guidelines, when biomining is not possible, capping or biocapping can be used as a preliminary or final termination measure. However, the guidelines do not specifically address "biocovers," instead classifying them as part of the broader category of capping[155].

- **SBM (Urban) 2.0 Toolkit**

  The SBM Urban 2.0 provides a valuable toolkit for remediating legacy dumpsites, specifically endorsing bioremediation and biocapping as viable solutions in situations where biomining is not feasible. It describes bioremediation as a process that stabilizes and breaks down biodegradable waste fractions through the action of microbes. SBM-U 2.0 provides step-by-step operational guidance for site assessments, community engagement, material handling, and monitoring protocols. The toolkit describes financing and convergence mechanisms, as well as resource mobilization schemes for urban development and waste processing. Biocovers do not appear explicitly in the SBM-U 2.0 toolkit, and it instead focuses on bio-remediation and biocapping as key landfill remediation methods[156].

3.2.1.8 Challenges & Barriers

- **Technical Challenges**

  Biocovers rely on microbial methane oxidation, which is highly dependent on environmental factors. Field research demonstrates that oxidation efficiency can range from 20% to 80%, depending on cover composition and climate circumstances[157]. In tropical regions like India, seasonal variations pose major challenges: during the monsoon season, intense rainfall saturates the cover, limiting the diffusion of oxygen, whereas in dry seasons, aridity inhibits microbial activity. Research shows that the rates of methane oxidation in landfills significantly decrease during dry periods compared to wet ones[158]. Moreover, durability is another concern, as organic substrates used in biocovers, such as compost and soil-organic mixtures, deteriorate within 6 to 7 years, which demands replenishment to sustain their effectiveness. Furthermore, maintaining optimal moisture, porosity, and oxygenation demands skilled measurements, but many municipal staff are frequently undertrained to effectively manage bioactive cover layers[159].

- **Economic Challenges**

  Unlike landfill gas-to-energy systems that can sell carbon credits or produce electricity, biocovers do not directly generate revenue. Although setup costs are relatively lower than those for installing gas extraction infrastructure, long-term monitoring and maintenance may significantly raise the financial burden. Moreover, continuous methane measurement requires gas flux chambers, sensors, and laboratory analysis, all of which are often unavailable to local governments in developing nations. This cost–benefit imbalance discourages adoption, as municipalities expect no immediate financial returns. While carbon credits under CDM and voluntary markets present a potential revenue stream, the technical requirements for monitoring and verification are highly demanding for implementation uptake.[160]

- **Institutional Challenges**

  Although biomining , bio-capping and bioremediation are mentioned in India's Solid Waste Management Rules (2026) and the CPCB's 2019 legacy waste guidelines, biocovers are not specifically defined or specified. Due to the lack of precise technical standards, urban local bodies are unable to provide recommendations on biocover system design, thickness, and monitoring procedures. Consequently, engineers adhere to conventional soil capping practices without recognizing the additional methane oxidation benefits of biocovers. Institutional capacity is further constrained by the fact that many municipalities rely on contractors who have little experience with microbial methane oxidation since they lack environmental engineers trained in landfill gas management . National programs such as SBM (Urban) 2.0 emphasize biomining and biocapping but do not explicitly promote biocovers, leaving them in a regulatory grey area[161].

- 3.2.1.9 **Opportunities for Biocovers in India**

  Biocovers are particularly suitable for legacy dumpsites and small- to medium-sized landfills with low gas yields where waste-to-energy (WTE) or landfill gas (LFG) capture systems are not economically feasible. In these situations, biocovers can significantly reduce methane emissions using simple compost–soil mixes at low capital cost and with locally available materials[162]. This makes biocovers an important option for solid waste management in many Indian cities, which already have large legacy and newly built landfill areas. The additional advantages of reduced odor and fire hazards also improve community acceptance of biocapped sites. The management of dumpsites is extremely difficult for smaller cities in India because of a lack of funding and technical resources. Large amounts of organic waste are produced in Tier-2 and Tier-3 cities, which can be turned into compost for use in biocovers. By installing biocovers in these cities, compost could be transformed into a tool for reducing methane emissions while simultaneously enhancing dumpsite stability. Moreover, pilot projects in smaller cities would give people confidence in the technology and useful operational experience[163].

3.2.1.10 Critical Assessment

Technically, biocovers are proven to oxidize significant amounts of landfill methane when engineering design, substance materials, and gas loads are well matched. In India, deployment on a large scale is primarily dependent on the availability of appropriate organic materials, such as green waste or municipal compost, which are readily available in many cities. Therefore, reliable compost supply chains and quality control are necessary for a successful large-scale deployment in order to guarantee the right porosity and stability[164].

Research indicates that biocovers are most effective when used as a temporary or stopgap measure. They provide quick, inexpensive methane reductions while more robust waste infrastructure (composting, segregation, engineered landfills, and WtE plants) is created. Although they cannot replace systemic changes, biocovers can fill the gap left by India's small landfills and legacy. In order to progress beyond temporary use of biocovers, policymakers need to establish standards for materials and monitoring, provide proper funding to reduce inspection costs, and specifically incorporate biocovers in technical regulations[165].

Although capping and bioremediation are mentioned in Indian waste regulations, biocovers are not specifically acknowledged as a specific methane mitigation option. Developing technical standards such as guidelines for active layer thickness, specifying material grades, and regulating monitoring protocols would build confidence among the engineering community. Financial incentives, such as central grants or carbon market facilitation funds, are required to cover monitoring costs.

3.2.2 Landfill Gas (LFG) Capture in India: Technology, Implementation Status, and Regulatory Alignment

3.2.2.1 Introduction to landfill gas (LFG)

Landfill gas is produced as a byproduct of waste decomposition in disposal sites, and it develops through microbial activity under anaerobic conditions. The gases produced by landfills are a mixture primarily composed of methane and carbon dioxide, with the exact proportions depending on waste and environmental conditions. Landfill gas poses significant environmental challenges due to its harmful components that possess high GWP[166][ccvii]. Landfill gas capture techniques, when properly implemented, considerably reduce GHG emissions and contribute to improving the air quality index[167].

Researchers emphasize its role in contributing to atmospheric pollution, but with proper management and proven scientific methods, it can be turned into a renewable energy source[168]. A site-specific collection network, gas treatment system, and constitutive utilization technologies are essential for successful engineering of landfill gas (LFG) projects. The economic feasibility of LFGs is determined by landfill size, gas productivity, and access to financing and energy markets[169].

Definition and Composition of LFG

Landfill gas typically consisted of a complex mixture of various gases, with its composition varying significantly. Normally, it comprises approximately 45% to 60% methane, a potent GHG, alongside 40% to 60% carbon dioxide, which is also a significant contributing factor to climate change[170]. In addition to these primary components, landfill gas contains trace amounts of other gases, including nitrogen, oxygen, ammonia, sulfides, hydrogen, and carbon monoxide. Moreover, it contains non-methane organic compounds (NMOCs), such as trichloroethylene, benzene, and vinyl chloride, which can pose environmental risks and health hazards. This highly complex composition emphasizes the importance of managing landfill gas effectively to mitigate its impact on the atmosphere and public health[171].

3.2.2.2 Climate Impact of Methane from Landfills

In India, annual methane emissions from landfills range from 1.25 to 1.68 teragrams, with some sites, including Ghazipur, emitting 15.3 gigagrams[172]. Waste sector emissions from unmanaged and poorly engineered landfills continue to contribute significantly to global anthropogenic methane emissions[173].

Although natural oxidation of methane in landfill cover soils contributes to partial mitigation, its effectiveness is limited by the availability of oxygen and specific soil conditions[174]. Therefore, the waste sector must actively capture and utilize landfill gas (LFG) to achieve significant and measurable emission reductions[175].

3.2.2 3 Importance of LFG Capture in Waste Sector Mitigation

Landfill gas (LFG) capture directly lowers GHG emissions by directly collecting methane produced during the anaerobic decomposition of organic waste at the dumpsites. This transformation not only allows for the systematic destruction of methane,, but also opens up opportunities for its utilization as a renewable energy source. Through such innovative solutions, we can significantly mitigate environmental impacts while contributing to sustainable waste management practices[176].

3.2.2.4 Technology Overview & Working Mechanism

Landfill gas technology focuses on capturing methane and other gases from waste decomposition. This approach converts harmful emissions from landfills into renewable energy sources, such as electricity[177]. Landfill gas technology is the engineered collection, treatment, and utilization of biogas produced by the anaerobic decomposition of organic waste in landfills. The gas mixture is primarily composed of methane and carbon dioxide, with traces of hydrogen sulfide, volatile methyl siloxanes, and other volatile organic compounds that determine the treatment needs[178]. Generation rates and gas quality are determined by waste composition, moisture content, temperature, and landfill operation history. Thus, technology pathways encompass three integrated functions: capture, cleaning, and energy conversion, or upgrading to pipeline-quality biomethane[180].

- **Design and Application Process**

  The design of a landfill gas (LFG) collection and control system (GCCS) is a complex engineering process that begins with an assessment of the site's waste composition and volume. With careful planning, landfill operations can minimize their negative effects on the environment, thereby promoting sustainable waste management practices. Engineers initiate this complex process by estimating the gas generation rate, a crucial step that serves multiple purposes: ensuring regulatory compliance, driving GCCS design, and evaluating the potential for energy recovery[181]. Widely recognized models such as the Landfill Gas Emissions Model (LandGEM) are often utilized to estimate total gas emissions, including methane, carbon dioxide, and non- methane organic compounds[ccxxvi]. The design can use a master plan for compliance with New Source Performance Standards (NSPS). A phased approach to landfill gas management is commonly adopted, enabling the optimization of capital investments while minimizing the necessity to abandon elements of the system as new layers of waste are deposited. This innovative approach ensures reliable gas flows and fosters a steady revenue stream through energy recovery initiatives[182].

- **Typical Components of LFG Systems**

  Landfill gas (LFG) collection and treatment systems comprise a series of interconnected components designed to extract, process, and thereby either safely destroy or utilize the generated gas. At the foundational level are the collection wells, which can be strategically positioned either vertically within the waste mass or horizontally within trenches during the landfill construction phase. These wells are precisely designed with perforations that facilitate the entry of gas and are connected to a comprehensive network of gas collection pipes, referred to as headers and laterals. These pipes efficiently transport the collected gas from the wells to a centralized processing point. To establish the essential negative pressure required for effective gas extraction, a blower or vacuum system is implemented. This critical component plays a vital role in promoting gas migration from the wells and ensuring that fugitive emissions do not escape into the environment. By maintaining a controlled atmosphere within the landfill, these systems not only enhance the efficiency of gas collection but also contribute significantly to environmental protection efforts by mitigating potential GHG emissions[183].

- **Step-by-step Working Mechanism**

  LFG can be captured, transformed, and used as a renewable energy source rather than escaping into the atmosphere. By utilizing LFG capture, methane is kept from entering the atmosphere and causing local smog and climate change, as well as preventing odors and other risks related to LFG emissions. The collection and processing of LFG to produce methane for multiple purposes is elaborated below in four steps[184]:

3.2.2.5 Methane Mitigation Potential

Landfill gas (LFG) capture is one of the most effective methane mitigation strategies in the waste industry, with potential reductions of up to 80% when open dumps are converted into sanitary landfills and organic waste is diverted to composting or biodigestion systems[185]. Empirical and modeling studies show that landfill gas-to-energy projects generally reduce net GHG emissions while producing usable electricity or heat. LFG can be captured and controlled actively to keep these potent GHGs from entering the atmosphere[186].

- **Emission Reduction Pathways (Flaring vs Energy Recovery)**

  Landfill gas (LFG) mitigation typically involves one of two approaches: flaring or energy recovery, each with its own set of environmental and operational implications.

  1. **Flaring:** This is the most common and straightforward method, which involves controlled combustion of LFG to convert highly potent methane (CH_4) into less harmful carbon dioxide (CO_2). The flaring process effectively destroys methane at high temperatures, significantly mitigating its greenhouse effect[187]. Enclosed flares are frequently preferred over open flares because this method achieves higher destruction efficiency and results in a lower release of volatile organic compounds (VOCs) and other harmful pollutants. This pathway is primarily concerned with environmental protection and is required in many areas for landfills that exceed certain size and emission thresholds[188].

  2. **Energy Recovery Systems:** The second approach, known as energy recovery, offers a dual advantage by effectively eliminating methane emissions while simultaneously reducing reliance on fossil fuels. Captured landfill gas (LFG) can be processed for various applications, such as generating electricity through internal combustion engines or gas turbines. Moreover, captured LFG can be used for supplying thermal energy for industrial and commercial use. More advanced methodologies can upgrade this gas to pipeline-quality renewable natural gas (RNG) using purification techniques like membrane separation or pressure swing adsorption. Although flaring serves as a straightforward and dependable means for methane destruction, energy recovery presents a more exhaustive and economically viable solution by converting waste gas into a revenue-generating resource[189].

- **Efficiency Levels under Engineered vs Open Dumpsites**

  Engineered landfills achieve better efficiency in capturing landfill gas through structured designs like liners and collection systems. Under controlled conditions, these systems can absorb up to 83% of methane emissions[190]. Final covers with low permeability and optimized wellfield designs help to achieve higher recovery rates, which frequently exceed 85% in closed sanitary landfills[192]. In contrast, open dumpsites in India have no recovery rates and lack the necessary infrastructure. For example, at the open site in Chandigarh, all methane produced is released rather than captured[193]. Engineered sites minimize gas escape by using isolation and venting. Open dumps have air ingress and leachate problems, which reduce potential yields[194].

Recent satellite studies reveal that global assessments significantly underestimate the methane emissions from open dumps by a factor of 5.3. This finding highlights the urgent need to transition to engineered waste management systems[194]. Open dumps' inability to maintain stable anaerobic conditions further exacerbates their inefficiency, leading to irregular gas generation and volatile emissions[195]. In contrast, engineered landfills facilitate the microbial oxidation of residual methane present in cover soils, thereby providing an additional layer of mitigation[196]. Consequently, upgrading open dumps to engineered landfills is a crucial strategy for achieving meaningful reductions in methane emissions within the waste management sector.

3.2.2.6 Co-benefits (odor control, fire prevention, health gains)

Odorous compounds, such as hydrogen sulfide, ammonia, and volatile organic compounds (VOCs), are commonly found in LFG and can lead to unpleasant odors and degraded air quality. Engineered collection systems effectively reduce the release of these gases by capturing them before they can escape into the atmosphere . Research indicates that bio-covers and active extraction systems can decrease odor emissions by more than 90%, which enhances community acceptance and ensures better environmental compliance[197].

Uncontrolled methane release poses a serious fire hazard due to its flammability and the potential for accidental ignition in oxygen-rich environments. Landfill gas (LFG) systems help mitigate this risk by maintaining anaerobic conditions and safely combusting the gas in flares or engines. Lowering surface emissions reduces the possibility of subsurface fires, which can cause long-term

structural damage to landfill cells and are difficult to extinguish. Moreover, reduced exposure to toxic trace gases and particulate matter associated with LFG has been shown to improve health. Health complications arising from LFG exposure have been linked to respiratory and neurological disorders in nearby populations. LFG capture improves ambient air quality and lowers disease burdens by reducing fugitive emissions, particularly in densely populated urban areas near waste disposal sites[198].

3.2.2.7 Cost Considerations

The cost of implementing landfill gas (LFG) capture systems can vary significantly based on several factors, including the specific conditions of the site and the complexity of the system. Cost-effectiveness is enhanced with economies of scale; bigger landfills with stable gas outputs accomplish reduced per-ton mitigation expenses as well as higher return on investment[199]. On the other hand, open dumpsites sometimes lack infrastructure, which makes restoration costly and less feasible without external financing[200].

- **Capital Expenditure Estimates**

  Establishing landfill gas capture systems in India demands significant upfront capital investments. This includes the installation of extraction wells, header pipes, blowers, and infrastructure for managing condensate to ensure effective gas collection[201]. For a mid-sized landfill of approximately 40 acres, the typical cost for a collection and flare system averages around $1.3 million, which translates to about $32,800 per acre when looking at global benchmarks[202]. However, in India, these costs are usually lower due to factors such as decreased labor costs and the availability of local materials[203].

  When it comes to systems that include energy recovery, the capital costs for internal combustion engines are roughly $2,300 per kilowatt of installed capacity, highlighting the significant financial outlay involved. The combined capital and operational expenses for landfills that recover energy can range from $17.03 to $46.16 per ton of waste processed, depending on specific site conditions. For instance, at Mumbai's Deonar landfill, the estimated total cost for closure, including gas management systems, is around $467 million, emphasizing the scale of investment required. These figures illustrate the necessity of conducting site-specific assessments to optimize financial planning and resource distribution. Pilot projects in Delhi have shown that initial setup costs can vary greatly depending on gas flow rates and the selected recovery technology. Ultimately, these capital expenditure estimates can support project feasibility when they are carefully weighed against the potential revenue generated from energy sales and the resulting environmental benefits.

- **Operational Expenditure and Maintenance Requirements**

  For medium-sized landfills, the initial capital investment is for engineered systems comprising components such as extraction wells, piping infrastructure, blowers, and flare or energy recovery units. These systems generally fall within the range of USD $400,000 to $5 million. In addition to the initial costs, ongoing operational and maintenance expenses, which encompass monitoring, management of condensate, and the replacement of treatment media, can lead to annual costs between USD $50,000 and $200,000[204]. It's important to note that energy recovery systems require a more substantial upfront investment due to the need for additional purification and electrical generation equipment. However, these systems can provide significant long-term financial benefits through revenue generated from electricity sales or the production of biomethane[205].

- **Economic Viability in the Indian Context**

  The economic feasibility of recovering landfill gas (LFG) in India is increasingly backed by empirical research showcasing favorable cost-benefit results. A case study conducted in Chandigarh found that MSW with more than 50% organic matter could produce 0.34 Gg/year of methane, facilitating electricity generation between 0.27 MW and 0.77 MW. This development offers considerable financial returns from energy sales and carbon credits. When applying these findings nationally, it is estimated that India's 3,184 dumpsites could collectively produce between 5,167 MW and 14,355 MW of electricity. This could result in annual financial gains ranging from 4.7 to 13 billion US dollars at current electricity prices[206].

Additionally, research conducted in Mumbai indicates that landfill systems equipped with gas recovery (LFSGR) can lead to significant cost savings when accounting for externalities like GHG emissions and land opportunity costs. Although India has a low per capita waste generation rate, its rapid urbanization and high organic content in MSW make LFG recovery particularly practical[207]. The potential for carbon financing, renewable energy incentives, and public-private partnerships further bolsters this viability. Consequently, incorporating LFG systems into India's waste management strategy offers a cost-effective solution for enhancing energy security and addressing climate change[208].

3.2.2.8 Global & Indian Case Studies

Global and Indian case studies demonstrate the technical feasibility and practical constraints of landfill gas capture and utilization. Numerous case studies from around the world show how LFG to energy projects can be implemented successfully, offering a clear model for waste-to-energy projects. The next section examines a few case studies from India and around the world that show the environmental advantages, economic feasibility, and technical viability of LFG systems:

International Experience (US, EU, CDM Projects)

International experience with landfill gas (LFG) capture demonstrates proven success in a variety of regulatory and operational contexts. Here's a breakdown of the key findings from the research focused on the global context:

- **US Experience:** The Environmental Protection Agency's (EPA) Landfill Methane Outreach Program (LMOP) plays a crucial role in promoting landfill gas (LFG) projects across the United States. This voluntary initiative has been successful in encouraging the development of numerous LFG energy projects. These projects have accomplished a significant reduction of methane emissions while generating clean, renewable energy[209]. In the United States, there are over 500 active landfill gas (LFG) energy projects that collectively generate more than 17 billion kilowatt-hours (kWh) annually. These projects benefit from federal incentives and strong environmental regulations. One notable example is the Puente Hills Landfill in California, which has achieved over 50 megawatts (MW) of electricity generation through advanced gas recovery and treatment systems[210].
- **EU Experience:** The success of the European Union is largely due to its strict regulations, particularly the EU Landfill Directive (1999/31/EC). This directive requires a reduction in the amount of biodegradable waste sent to landfills

01
The gas is first treated by passing it through a knockout pot, filter, and blower, which removes moisture.

02
Secondary treatment consists of using an aftercooler or other additional moisture removal (as needed), followed by siloxane/sulfur removal and compression (as needed).

03
Following the removal of impurities in the Secondary Treatment stage, the LFG can be used to generate electricity or as a medium-Btu fuel for arts and crafts or boilers.

04
Advanced Treatment compresses the LFG into a high-Btu gas that can be injected into a gas pipeline or used as vehicle fuel after removing additional impurities (CO_2, N_2, O_2, and VOCs). Waste or tail gas is directed to a thermal oxidizer or flare.

and mandates high operational and technical standards, including the implementation of gas management infrastructure. As a result of this directive, there has been a significant decrease in landfilling and an increase in landfill gas (LFG) capture and utilization across EU member states[211]. Within the European Union, countries such as Germany and the Netherlands have enforced comprehensive landfill regulations, requiring waste pre-treatment and proactive gas collection, leading to methane capture efficiency of 90%[212].

- **CDM Projects:** Clean Development Mechanism (CDM) projects have significantly enhanced landfill gas (LFG) recovery efforts in developing countries. For instance, the Loma Los Colorados landfill in Chile, which is CDM-registered, increased its electricity generation capacity from 2 MW to over 11.89 MW and has plans to add another 21.78 MW, showcasing both scalability and the potential for climate finance. Similarly, the Cartagena landfill project in Colombia has achieved annual reductions of 129,553 tCO_2e by implementing flare and energy recovery systems. These cases illustrate the critical roles of policy support, technology transfer, and carbon financing in promoting global methane mitigation through effective LFG systems[213].

Indian Case Studies: Ghazipur, Gorai, and Other Pilots

Indian case studies at Ghazipur, Gorai, Deonar, and other pilot sites demonstrate both the technical feasibility of landfill gas recovery and the ongoing operational, financial, and institutional barriers to project expansion. Below is a brief overview of all these studies:

- **Ghazipur Landfill:** The Ghazipur landfill in Delhi, one of the oldest and largest municipal solid waste (MSW) facilities in India, serves as a vital case study for landfill gas (LFG) recovery measures. After more than three decades of waste accumulation, the site is rich in biodegradable organic materials, making it a significant contributor to methane emissions under anaerobic conditions. Researchers utilizing the First Order Decay (FOD) model have estimated the potential for methane generation at 15.3 Gg/year, which represents about 1-3% of the total methane emissions from landfills across India[214]. Plans are in place for landfill mining and gas recovery at this site, specifically dedicating a ten-acre section to the Gas Authority of India for methane extraction and energy conversion. Although there are infrastructural obstacles, the site showcases considerable technical feasibility for capturing and utilizing LFG, particularly when coupled with refuse-derived fuel (RDF) systems[215].
- **Gorai Landfill:** The Gorai landfill in Mumbai is well known as an effective case study for India's sustainable landfill gas (LFG) use and scientific remediation. The site, which had a dumping history that began in 1975 and contained over 6 million tonnes of waste, was closed in 2008 and retrofitted with a gas capture system that included 48 vertical wells, a 2.4 m top lining system, and HDPE piping for extraction and conveyance. The LandGEM tool from the US EPA was used to model methane generation. Recovery rates of 1840 m^3/hr were estimated, and methane made up roughly 50% of the LFG volume[216]. The site was converted into a 19.6-hectare green space after closure, which lowered fire hazards, odor, and public health risks while earning money through CERs. The success of Gorai has influenced future landfill closure efforts throughout India, emphasizing the significance of integrated design, climate funding, and municipal leadership in methane reduction and sustainable urban redevelopment[217].

3.2.2.9 Current Status in India

Despite being one of the world's biggest producers of landfill methane, India's landfill gas (LFG) capture infrastructure is still in its beginning stages, with only a limited number of systems currently in operation[218]. Strengthening institutional capacity and incorporating LFG capture into national waste management policies is critical for increasing methane mitigation[219].

Extent of LFG Capture Implementation

The implementation of landfill gas (LFG) capture in India is significantly limited, despite the country's considerable potential for methane emissions arising from over 2,000 active dumpsites as per CPCB 2022-23. By 2025, only a select few engineered landfills in cities such as Delhi, Mumbai, Ahmedabad, and Pune have initiated partial LFG recovery systems, mainly through pilot initiatives or donor-supported funding[220]. Particularly, the Gorai landfill in Mumbai is the sole site that has incorporated a complete closure and gas capture system supported by carbon credits. However, other sites such as Ghazipur and Pirana are still in the feasibility assessment stage or in the early stages of implementation[221].

India does not have a comprehensive policy for the recovery of landfill gas (LFG), and the majority of municipal solid waste (MSW) is dumped in unlined, improperly managed sites that lack gas extraction systems. The Bureau of Energy Efficiency (BEE) has implemented methods that conform to the UNFCCC's ACM0001 for both flaring and energy recovery, but the adoption is inconsistent and largely reliant on outside funding or private partnerships. Alternative technologies such as microbial methane oxidation systems (MMOS) and landfill mining (LFM) are becoming more popular for older sites, although they are still largely in experimental phases. Overall, the degree of LFG capture in India is lower compared to the scale of waste production, emphasizing the necessity for cohesive policies, financial incentives, and capacity development to enhance methane mitigation strategies[222].

State-level audits also reveal a lack of qualified staff and limited institutional capacity for putting gas recovery technologies into practice. Emerging technologies such as landfill mining and microbial methane oxidation systems (MMOS) are being piloted, but CPCB observes that scalability is restricted by fragmented governance and limited funding mechanisms. These findings highlight the urgent need for comprehensive policy reform, technical capacity building, and enforceable LFG recovery targets[223].

3.2.2.10 Policy & Regulatory Landscape

Solid Waste Management Rules 2026

The rules explicitly require methane capture infrastructure however the urban local governments face capacity and funding constraints, making it difficult to comply with scientific landfill design and monitoring protocols. The SWM Rules 2026 are a foundational policy tool, but their effectiveness is contingent on strong enforcement, stakeholder participation, and integration with climate and energy policies. Strengthening these dimensions is critical to implementing LFG recovery and transitioning to sustainable waste management[224].

CPCB Guidelines on Legacy Waste (2019)

Guidelines on Legacy Waste (2019) provide a specialized framework for the scientific management and disposal of decomposing municipal solid waste in India's old landfills[225]. These guidelines mainly provide for biomining, a systematic process of digging, treating, and segregating legacy waste to conserve valuable resources and land[226]. The process is designed to recover recyclables and high-calorific-value refuse-derived fuel, while soil-like fines are used for landscaping or landfill cover material[227]. A major factor highlighted in the guidelines is the regulation of landfill gas (LFG), since digging up and aerating old waste can lead to a considerable release of trapped methane and other gases[228].

The guidelines also impose legal responsibilities on urban local authorities to ensure the timely and proper closure of these waste sites, which is essential for preventing further environmental harm. Therefore, the CPCB guidelines indirectly promote the conditions required for the eventual and sustainable use of LFG from restored locations, even though the primary focus is on remediation. Nevertheless, despite this forward-thinking framework, a significant obstacle persists in practical implementation, as numerous municipalities lack the necessary technical know-how and financial resources for successful biomining operations[229]. The CPCB framework is a paramount step for sustainable landfill management; however, its success relies on effective interdepartmental coordination, enhanced capacity building, and collaboration with climate and energy policies to facilitate landfill gas (LFG) recovery and promote circular economy transitions[230].

3.2.2.11 Challenges & Barriers

Despite progressive policies and pilot successes, India's landfill gas (LFG) recovery efforts face ongoing challenges. Inadequate infrastructure, fragmented governance, limited technical capacity, and insufficient financial mechanisms are among the primary barriers. These constraints impede large-scale implementation, postpone methane mitigation, and undermine the transition to sustainable waste management and climate-friendly urban development.

Technical Challenges

Landfill gas (LFG) capture in India presents significant technical challenges due to site heterogeneity, poor landfill design, and limited operational control. The majority of (MSW) sites are unlined dumps with inadequate containment, making it difficult to install leachate management systems and gas extraction wells[cccx]. Research from Chandigarh and Pimpri-Chinchwad shows that irregular waste composition and moisture levels cause methane emissions to fluctuate seasonally and geographically, making precise modeling and recovery system design more challenging[232].

Models like FOD, MTM, and LandGEM produce inconsistent outputs because of input variability and uncertainty, making methane generation estimates unreliable in the absence of standardized waste characterization protocols[233]. Additionally, the vertical expansion of dumpsites that are more than 60 meters in height presents structural hazards and restricts the safe drilling of gas wells. Insufficient source segregation further diminishes the organic fraction required for continuous methane production, thereby compromising the potential for energy recovery. Among the operational difficulties are low suction efficiency, gas leaks, and extraction infrastructure corrosion brought on by high moisture and acidic leachate conditions. These technological limitations require the implementation of alternative technologies, such as microbial methane oxidation systems (MMOS) for legacy sites, site-specific engineering solutions, and reliable monitoring systems[234].

Economic Challenges

India's solid waste management faces financial difficulties due to inadequate municipal budgets, which restrict the development of infrastructure for collection and processing[235]. Local governments are under pressure due to the high costs of waste handling, which range from Rs. 500 to Rs. 1500 per tonne, with 60–70% of the funds going to waste collection alone[236]. Financial limitations prevent the use of cutting-edge technologies, such as biomining, for legacy waste, which frequently costs more than Rs. 1000 per tonne to remediate[237]. Unplanned fiscal policies contribute to funding gaps, resulting in a reliance on insufficient central grants, such as those provided under the Swachh Bharat Mission[238]. While the unorganized informal sector saves municipalities Rs. 24,500 per tonne through recycling, its poor integration leads to economic inefficiencies.

Low user fees and the absence of waste taxes fail to generate sustainable revenue, with an estimated Rs. 50,000 crores of potential collections currently untapped[239]. Organic waste management faces challenges due to collection fees, which burden households and decrease participation rates[240]. Additionally, the remediation of legacy dumpsites involves high capital costs, ranging from Rs. 20 to 50 lakhs per acre, which deters private investments[241]. Socioeconomic disparities further increase costs, as low-income areas tend to generate more unmanaged waste, consequently raising public health expenditures. Overall, these challenges point out the need for innovative financing solutions, such as public-private partnerships, to achieve the goals of a circular economy[242].

Institutional Challenges

Institutional challenges in India's municipal solid waste management include fragmented governance and overlapping roles between central, state, and urban local bodies[243]. Delays in action plans and ground-level execution result from a lack of coordination between these levels[244]. Effective waste management techniques are limited by the lack of committed, trained personnel and training in urban local bodies[245]. Due to inadequate monitoring mechanisms, regulations such as the Municipal Solid Waste Rules 2000 are still not adequately enforced[246]. Lack of funds further limits waste processing technology integration and infrastructure improvements[247]. The unorganized sector, which includes rag-pickers, is not acknowledged despite their contribution to the annual 14% decrease in municipal expenses[248]. Moreover, public opposition interferes with the selection of new landfill sites and overloading existing facilities[249]. Socio-cultural factors and low public awareness slow down source segregation efforts[250]. Cultural and infrastructural constraints further complicate optimization of management systems. Overall, to achieve long-term success, these challenges necessitate capacity building and integrated approaches[251].

Public Acceptance and Perception Issues

Public acceptance poses a significant challenge to landfill gas (LFG) recovery in India, primarily due to limited knowledge, distrust in municipal authorities, and negative views about waste management infrastructure. Research indicates that communities near landfills often link LFG projects to increased nuisances, triggering fears about odors, fire dangers, and health concerns stemming from past mismanagement[252]. In cities such as Delhi and Mumbai, residents have opposed landfill rehabilitation efforts, pointing to a lack of transparency and insufficient engagement with stakeholders[253].

The lack of focused communication campaigns worsens misinformation, leaving many citizens unaware of the environmental and energy advantages of methane recovery. Studies show that involving the community in the planning process and providing education can significantly enhance public backing for waste-to-energy projects[254]. However, most urban local bodies (ULBs) do not have the necessary frameworks to integrate public input into project development or assessment. Cultural perspectives on waste also play a role in acceptance, as informal waste workers often view LFG systems as a threat to their livelihoods, fearing displacement from their traditional scavenging activities[255]. To address these issues, it is essential to implement inclusive governance, foster trust-building efforts, and establish demonstration projects that visibly enhance local conditions. Without community support, even well-designed LFG systems may be underused or neglected.

3.2.2.12 Suitability & Conclusion for the Indian Context

Capturing landfill gas is well-suited for India's waste management due to the high organic matter in municipal solid waste. Indian landfills, such as Ghazipur, have the potential for energy recovery despite their lack of proper management practices. The suitability for this method increases in urban regions where waste is growing rapidly and there are few new sites available. LFG capture provides sustainable solutions but necessitates policy enforcement and improvements to infrastructure across the country[256].

Limitations under Indian Conditions

Although it carries significant potential, LFG capture in India encounters various challenges. Many landfills are poorly managed, lacking proper engineered containment, leachate management, and infrastructure for gas extraction. The variability in waste composition and seasonal moisture changes complicates methane modeling, resulting in decreased recovery efficiency[257]. Financial limitations and the absence of feed-in tariffs disrupt energy monetization, while the limited technical expertise of urban local bodies (ULBs) complicates system design and management[258]. Additionally, public objections stemming from odor issues and a lack of trust in municipal governance further slowdown implementation. Furthermore, fragmented regulatory oversight and the absence of mandatory methane recovery targets affect enforcement and scalability[259].

Opportunities for LFG in India

Despite the challenges, LFG capture offers significant opportunities through supportive government policies and the enormous potential of urban waste sources. The government's wider focus on 'Waste-to-Energy' creates a supportive policy environment, backed by significant investments in the energy sector[260]. The Government of India's decision to consider LFG as a source of income that can draw in much-needed private investment and close current financial gaps marked a significant policy change when it started the process of lifting an earlier ban on organic waste[261].

3.2.2.13 Critical Assessment

From a technical perspective, while LFG capture has been demonstrated to be effective, achieving long-term success in India relies on site remediation, accurate yield estimation, and stable long-term operations[262]. On the economic side, many projects require a combination of financing and policy assurances because revenues from electricity or biomethane alone are often insufficient[263]. Institutionally, defining roles, establishing dedicated state units, and simplifying approval processes will help lower transaction costs and draw in private investment[264]. From a social standpoint, transparent stakeholder consultations, fair benefit-sharing, and safeguarding informal recyclers are crucial for gaining community approval and ensuring project legitimacy[265]. In short, implementing phased pilot projects, adopting conservative monitoring, reporting, and verification (MRV), undertaking clustered remediation, and aligning energy and climate incentives can unlock the mitigation advantages of LFG and the associated energy benefits in India.

Conclusion

India has significant potential for capturing landfill gas, with the ability to produce as much as 14,355 MW of renewable energy each year from urban landfills. This presents a dual advantage: reducing potent GHG emissions while providing a new source of clean energy. However, the broad implementation of these initiatives encounters considerable challenges due to the absence of a unified national policy and institutional capabilities. Policy instruments such as the SWM Rules (2026), CPCB's Legacy Waste Guidelines (2019), and SBM-U 2.0 Toolkit offer frameworks but lack mandatory LFG capture provisions. Financial obstacles, including substantial initial capital expenses and a lack of dedicated green financing options, also discourage private sector involvement. However, there are prospects for advancement in the renewed emphasis on solid waste management regulations and decentralized waste-to-energy initiatives. Ultimately, a strong and committed national policy framework is crucial to address these systemic challenges and fully harness India's considerable landfill gas potential.

3.2.3 Waste-To-Energy - Focusing on Landfill Management: Incineration

Waste incineration is a thermal treatment that reduces solid waste volume and mass through high-temperature combustion, yielding ash and flue gases. When coupled with energy recovery, it becomes a Waste-to-Energy (WtE) system, generating electricity or steam. India increasingly promotes WtE plants as a crucial landfill diversion and urban waste management strategy.

Table 21: Comparison on Incineration Technologies

Aspect	Simple Incineration	Waste-to-Energy (WTE) Incineration
Primary Purpose	Volume reduction of waste	Volume reduction plus energy recovery
Output	Ash and emissions	Electricity, heat, ash, and emissions
Energy Recovery	No	Yes — typically through steam turbines or cogeneration
Efficiency	Low (waste just burned)	Higher (energy harnessed from combustion process)
Infrastructure Requirements	Basic incinerator setup	Advanced setup with energy recovery units (boilers, turbines, generators)
Cost	Relatively lower upfront cost	Higher capital and maintenance cost
Regulatory Scrutiny	Relatively lower (but changing)	Higher due to dual functions and pollution concerns
Ash Handling	Requires disposal	Requires disposal (amount may vary based on efficiency)

3.2.3.1 Simple Incineration - (Without energy generation)

Incineration is a thermochemical process involving controlled combustion of waste at high temperatures (typically 850°C–1100°C) to convert organic matter into ash, flue gases, and heat. Waste incineration refers to the burning of solid waste at high temperatures in a controlled environment. Incinerators are furnaces designed to handle waste materials. This process significantly reduces the volume of waste (by up to 95%) and reduces its mass (by 80-85%). It's a common method of waste treatment used for various solid waste streams including municipal solid waste (MSW) (household trash), medical waste, and some hazardous wastes.[266]

3.2.3.2 Critical Analysis of Waste Incineration (w/o energy generation) for MSW in India

Table 22: Critical analysis of waste incineration without energy generation for MSW in India

Category	Aspect	Description
Advantages	**Volume Reduction and Waste Destruction**	Considering India's daily generation of over 170,000 tonnes of MSW (CPCB 2022-2023), the primary advantage of waste incineration is its significant **volume reduction capability.** This is particularly critical in **densely populated urban areas** facing severe land scarcity for disposal, and in regions anticipating a surge in waste generation, as it effectively destroys the accumulated waste.
	Landfill Diversion and Methane Abatement	Compared to landfills, incineration utilizes less space and eliminates on-site waste degradation, thereby preventing the generation of **methane** from mixed or organic waste.[267] This addresses both economic and environmental impacts associated with landfills. Furthermore, under the oxidative combustion conditions in MSW incinerators, methane is not present in the waste gas and is consequently not emitted.[268]
Concerns	**Atmospheric Emissions and Public Health Impacts**	Release of particulate matter emissions (PM_{10} and $PM_{2.5}$) has been underscored as the primary concern with MSW incineration plants. A July 2022 study on safe buffer distances for Chinese waste-to-energy facilities found hazard-index and cancer-risk figures were above safe levels 1,000 metres downwind of 510 incinerators. The study concluded that a buffer distance of at least 1,500 metres is necessary to reduce risks to an acceptable level. That is five times the current required distance of 300 metres.[269] Studies also found that proximity to waste incineration may increase risks of cancer, birth defects, and other adverse health impacts. Often, low-income and communities of color bear the brunt of this toxic burden, with 80% of U.S. municipal solid waste incinerators situated in communities where more than 25% of people identify as "minority," living below the federal poverty rate, or both. Beyond localized impacts, there can be far-reaching consequences as well. Many pollutants released from waste incineration—such as dioxins, PFAS, and mercury—are persistent organic pollutants that accumulate in people and wildlife worldwide. Research shows U.S. municipal waste incineration has contributed up to 70–80% of dioxins found in remote regions like the Arctic.[270]
	Elevated Capital and Operational Costs	Constructing and operating incinerator facilities is a costly undertaking, with expenses significantly increased by the need for advanced pollution control equipment and the safe disposal of toxic ash. Operating costs can range from $30–$50 per ton for smaller, less regulated plants, to $100–$300 per ton for modern facilities with stringent environmental controls.[271] China has certain lower-cost plants, especially those in smaller or less affluent cities, may operate for as little as $2.60 per ton of waste, but these often have inferior pollution controls compared to higher-cost, advanced facilities found in major cities.[272] Where these plants are newly introduced, the costs of training personnel also add up.
	Residue Ash Management Challenges	Bottom ash from municipal solid waste incineration typically constitutes 25–30% of the input mass and contains elevated levels of hazardous heavy metals, exceeding WHO permissible limits for soil. Improper disposal of this ash, such as dumping in landfills without adequate treatment or monitoring, poses significant risks of soil and groundwater contamination and public health hazards.[273] Ash management facilities remain inadequate in India, thus most of it ends up back in landfills (ironically!) and pollutes the local environment.

Category	Aspect	Description
	Detriment to Circular Economy Principles	Readily available incineration facilities can discourage efforts to reduce waste generation and prioritize recycling, ingraining the opinion of stakeholders that all produced waste can just be burnt away. Each type of material in municipal solid waste has an ecologically optimal disposal/treatment route (meaning its most sustainable way of being discarded and processed), which is nearly always recycling. This includes traditional mechanical recycling as well as organics recycling such as composting or anaerobic digestion. Not only are these methods more environmentally and resource conscious but also conserve energy and are cost-efficient.[274]
	Contribution to Climate Change and SLCP Emissions	The incineration of municipal waste involves the generation of climate-relevant emissions. These are mainly emissions of CO_2 (carbon dioxide) as well as N_2O (nitrous oxide), NO_x (oxides of nitrogen), NH_3 (ammonia), and organic C, measured as total carbon. The particulate emissions ($PM_{2.5}$) from incineration plants can also contain heavy amounts of black carbon.

Inference:

Considering the significant disadvantages of waste incineration, it should not be prioritized as a method of waste management and landfill reduction (as is being done in China).

However, in certain cases this may come out as the only viable alternative, particularly when all useful resources have been bio-mined and/or alternate waste management methods remain inaccessible. In this case, certain important guidelines must be followed: appropriate selection of sites (ideally away from densely populated areas); waste input and control; and techniques for combustion, flue gas, solid residue and effluent treatment. Best environmental practices (BEP) for waste incineration include appropriate offsite procedures (such as overall waste management and consideration of environmental impacts of siting) and appropriate onsite procedures (such as waste inspection, proper waste handling, incinerator operation and management practices, and handling of residues).[275] Where deployed, regulators must ensure that emission limits are set (particularly for air pollution), and efficient monitoring devices, such as CEMS, are installed to actively penalize mismanagement at incineration facilities.

3.2.3.3 Waste Incineration - (With energy generation)

Waste-to-Energy (WtE) incineration, converting MSW into electricity via controlled combustion, is aggressively promoted in India for landfill reduction and renewable energy generation, capable of cutting waste volume by up to 90%. However, its efficacy in India is debated due to the **low calorific value of Indian waste,** significant **environmental concerns** (including toxic emissions from unsegregated waste and challenges with ash disposal), and a history of **operational and financial failures.** While the process aims to reduce landfill use and potentially lower GHG emissions, its real-world impact hinges critically on waste composition, plant design, and stringent pollution control enforcement.

Table 23: Critical assessment of incineration-based waste-to-energy in India

Critical Assessment of Incineration-based Waste to Energy in India	
Aspect	**Description**
Technical Unsuitability: Waste to Energy does not fit the Indian waste profile.	**Low Calorific Value:** A fundamental challenge for WTE incineration in India is the composition of its municipal solid waste (MSW). Indian MSW typically has a high moisture content, ranging from 40% to 52%, and a low calorific value, often between 800-1100 kcal/kg.[276] This is significantly lower than the desirable range of 1500-2400 kcal/kg required for efficient incineration.[277]
	High Moisture Content: The high moisture content makes the waste unsuitable for thermo-chemical conversion, as excessive heat is needed just to remove moisture, leading to inefficient energy recovery.[278] Consequently, self-sustaining combustion often cannot be achieved, necessitating the use of auxiliary fuel, which adds to emissions and costs.
	Unsuitable Waste Composition Furthermore, organic matter constitutes a large portion (40-60%) of Indian MSW, which is ideally suited for biological processing like composting or biomethanation rather than incineration.[279]
Operational Inefficiencies and Adverse Environmental Impacts: *Many WTE plants in India operate below their stated capacity.* *The practice of mass incineration disincentivizes source segregation and alternate waste management practices, leading to significant environmental issues.*	**Air Pollution:** WTE incinerators release toxic emissions, including dioxins, furans, heavy metals (lead, cadmium, mercury, arsenic, chromium), acid gases (HCl, SO_2, NO_x), particulate matter (PM_{10}, PM_2.5), and volatile organic compounds. Dioxins are highly toxic, impacting reproductive and developmental systems, immune function, hormones, and causing cancer. Methane, a potent GHG (21 times stronger than CO_2), is also linked to landfills, which WTE aims to reduce[280]. Inspections of Delhi's WTE plants revealed gross violations of emission standards: the Okhla plant emitted 890% more dioxins/furans and 296% more hydrogen chloride than permitted, while Narela-Bawana showed 390% higher dioxins/furans. Moreover, India's emission standards for WTEs are more lenient than European standards, yet even these are frequently violated[281].
	Hazardous Ash Generation: Incineration produces hazardous ash as a residue, typically around 20% of the treated waste's original volume. This ash, laden with heavy metals and toxic chemicals like dioxins and furans, requires specialized disposal in well-designed and operated landfills to prevent soil and water contamination. Improper disposal poses significant environmental and health risks.
	Public Health Impacts: Communities living near WTE plants and dumpsites report major health problems, including higher prevalence of respiratory illnesses, eye infections, stomach problems, fever, and headaches. The Deonar dumpsite in Mumbai, for instance, already presents hazardous levels of air and water pollution, which will be further exacerbated by the proposed WTE plant[282].
	Economic Unviability: WTE plants are financially burdensome, characterized by very high capital investment due to expensive imported machinery and sophisticated pollution control devices. They also incur high operational and maintenance (O&M) costs, which often leads to high tariffs on electricity. For example, WTE-generated electricity typically sells at Rs. 6-8 per unit (kWh), making it one of the most expensive forms of electricity, significantly higher than thermal, solar, or wind power[283].
Policy Priority and Financial Incentivization: *Despite the inherent challenges and a history of failures, the Indian government actively promotes WTE technology, often neglecting more sustainable waste management practices.[286]*	**Public[284]-Private Partnership (PPP) Model:** WTE plants in India are primarily established under a Public-Private Partnership (PPP) model, involving long-term contracts (20-25 years) between municipal corporations and Special Purpose Vehicles (SPVs). These SPVs, created by parent companies to isolate financial risk, are often granted public land at nominal costs. This model, while intended to leverage private sector dynamism, has been criticized for its lack of transparency, potential for corruption, and placing financial burdens on public funds while allowing private firms to minimize risks and maximize profits. Concession agreements often guarantee a minimum waste quantity, penalizing urban local bodies (ULBs) if not met, which discourages source segregation.
	Extensive Subsidies and Compulsory Power Purchase: The government provides **substantial financial incentives** for WTE projects due to their high costs. These include: • Viability Gap Funding (VGF): Up to 35% of project costs from the Union government under schemes like SBM. • Grants from MNRE: Up to Rs. 5 crore/megawatt, with a maximum of Rs. 50 crore/project • Loans from Public Financial Institutions: Projects like Okhla WTE heavily rely on loans from institutions like Power Finance Corporation of India. Additionally, electricity distribution companies (DISCOMS) are mandated to compulsorily purchase 100% of the power generated by WTE plants at high, pre-determined tariffs[285].
	Ignoring Failures and Policy Contradictions: Despite a long history of WTE failures in India—including plants in Delhi (Timarpur 1989, Ghazipur 2007), Hyderabad (1999), Vijayawada (2003), Lucknow (2003), Nalgonda (2008), and Bangalore (2005)—the government continues to push for new WTE installations. Policy documents, such as the Solid Waste Management Rules 2016 and the Manual on Municipal Solid Waste Management[287] 2016, formally prioritize waste prevention, reuse, recycling, and composting, ranking WTE low in the waste management hierarchy. However, in practice, government investment and political impetus remain disproportionately focused on large-scale WTE projects, contradicting these stated priorities.

Way Forward: A Call for Sustainable Alternatives

In conclusion, WTE incineration, as currently implemented in India, is a false solution to the waste management crisis. It is costly, polluting, and fundamentally incompatible with the composition of Indian municipal solid waste. The heavy government investment, subsidies, and lenient regulations supporting WTEs are misdirected public funds that fail to address the root causes of waste generation and perpetuate environmental and public health hazards . Instead of relying on this unsustainable technology, India needs to re-examine its approach to waste management and focus on holistic, long-term, and decentralized solutions.

Waste-to-Energy (WTE) Technology Limitations:

High moisture content and low calorific value of most Indian municipal solid waste (MSW) make incineration inefficient without significant preprocessing. Many WTE plants experience operational issues, emission violations, and public opposition, with some even shutting down due to technical or financial failures. The absence of reliable source segregation further reduces plant efficiency and escalates operational costs.

3.2.3.4 Conclusion: Feasibility of Waste-to-Energy in India

Waste-to-energy sits at the very bottom of the waste value chain and directly undermines the principles of a circular economy. By burning materials that could otherwise be recovered, recycled, or biologically treated, it locks in a linear 'burn-and-dispose' pathway, eroding incentives for segregation and resource recovery. This structural misfit makes WtE less a solution and more a diversion from India's stated goals of material circularity and landfill reduction.

In practical terms, decades of experimentation have already shown that WtE incineration has limited feasibility in the Indian context. Plants consistently underperform, face recurring financial and operational failures, and create environmental risks that remain unresolved, such as toxic ash disposal and harmful air emissions. Despite heavy policy push, WtE has not proven to be a scalable or reliable solution. At best, it can be considered in very selective cases, dense metropolitan cores with severe land scarcity, strict regulatory oversight, and guaranteed high-calorific waste streams.

India's waste policy priorities, especially the **Garbage Free Cities target by 2026** and the long-term vision of a **zero-landfill future by 2030,** demand a very different trajectory. Proven pathways, egregation, composting, biomethanation, and material recovery, are both economically viable and environmentally aligned with circularity. If India is to avoid repeating the cycle of costly WtE failures, policy must explicitly acknowledge the marginal role of incineration and redirect focus toward systems that truly close resource loops.

3.2.4 Bio-mining, Bioremediation and Bio-Capping

3.2.4.1 Introduction:

Bio-mining involves a systematic process of excavation, drying, screening, and segregation of municipal solid waste accumulated in dumpsites into distinct fractions—recyclables, Refuse-Derived Fuel (RDF), compostable organics, and inert materials. The recyclables, such as plastics and metals, are processed and sent to authorized recycling facilities, while RDF is typically used as an alternative fuel in cement kilns or WtE plants. Compostable fractions, which include partially degraded organic matter, are stabilized through biological treatment and utilized for land reclamation or converted into compost, depending on the quality and contamination levels of the input material. The inert fraction, which forms a significant portion of the bio-mined output, is increasingly being utilized in infrastructure development—particularly as embankment fill material or subgrade in road construction. This application has been successfully demonstrated in projects such as the Delhi–Mumbai Expressway and the Ahmedabad–Dholera Expressway, with studies by the Central Road Research Institute (CRRI) and policy guidance from the Ministry of Road Transport and Highways (MoRTH) endorsing the viability of this reuse pathway.

3.2.4.2 Phases of the biomining process

Table 24: Phases of the Biomining process

Phase	Description
Phase 1: Stabilisation	– Legacy waste is arranged into windrows and regularly turned. – Treated with bio-cultures and deodorisers. – Reduces moisture, odour, pathogens, and overall volume by 35–40%. – Stabilisation is confirmed via germination tests and absence of heat, leachate, or gas.
Phase 2: Sorting & Segregation	– Stabilised waste is screened using trommels and manual labour. – Separated into components like soil, stones, construction debris, and combustible materials.
Phase 3: Disposal	– Non-combustible materials used for earth filling or in aggregate processing. – Combustible materials (Refuse Derived Fuel or RDF) are sent for co-processing, typically in cement kilns.

Bioremediation, often deployed alongside bio-mining, involves the use of microbial consortia or other biological treatments to stabilize organic matter and degrade harmful pollutants present in legacy waste. It is particularly effective for reducing odour, leachate formation, and pathogenic risks in older waste deposits. According to the CPCB Guidelines (2019), this biological treatment can reduce waste volume by 35–40% through moisture loss and microbial degradation. These techniques have gained traction due to their alignment with the SBM 2.0, which mandates the scientific remediation of over 3,000 dumpsites across India. Companies have implemented biomining at scale, using trommel screens, magnetic separators, and sand washing systems to recover materials of value and reclaim land for future use. Post-remediation steps include land levelling, planting of trees using and long-term environmental detoxification through landscape restoration and controlled reuse.

Biocapping: Bio-capping, involves placing a multi-layered cover over the remediated or residual waste. This cover typically includes layers of compost-amended soil, geomembranes, and a vegetative layer.[288] The objective is to prevent rainwater infiltration, reduce surface methane emissions, and restore the site's aesthetic and ecological value. Bio-capping is essential in situations where full waste excavation is not possible or desirable, for example, due to land constraints or high environmental risk. This method is endorsed under India's SWM Rules, 2026, as a closure strategy for dumpsites.[289] When implemented correctly, bio-capping can transform a hazardous landfill into a green space or community zone, offering ongoing environmental benefits.

3.2.4.3 Operational and Capital Expenditure for Bio-mining and Bioremediation

The operational cost of bio-mining and bioremediation varies with the scale of the dumpsite, with the Central Pollution Control Board (CPCB) estimating on-site treatment expenses at approximately ₹400–₹700 per cubic metre, excluding capital investments.[290] In most ongoing projects across India, mobile equipment is used to enhance flexibility and efficiency, with the capital cost partially borne by the service users. Advanced bio-mining setups often deploy programmable logic-controlled (PLA-based) systems to automate and optimise the transfer of stabilised waste between screening units. The capital expenditure for a mobile processing unit with a daily capacity of around 700 tons is estimated to be in the range of ₹10 crore.

Bio-Capping

Where bio-mining is not feasible, bio-capping with impermeable layers and vegetation is used to minimize infiltration, gas escape, and exposure. **Bio-capping** is a method of rehabilitating dumpsites by converting them into green spaces such as parks or woodlands, effectively stabilising waste into durable landscapes. The process involves covering the waste with layered materials, typically including soil and vegetation, to physically isolate the contaminants from the surrounding environment. Commonly used for sites containing large volumes of waste with relatively low toxicity, capping does not eliminate the pollutants but contains them in place, preventing their spread. When designed appropriately, capped sites can be repurposed for limited public or ecological use, such as open green areas.

According to the National Institute of Urban Affairs (NIUA) and Central Pollution Control Board (CPCB) guidelines, scientific capping involves a multi-layer system: a compacted clay or HDPE barrier, a drainage layer, and a vegetative cover to prevent infiltration and erosion, while supporting surface vegetation.

The key elements for process management and monitoring include:

Leachate and Gas Management: Scientific landfills and remediated dumpsites are equipped with leachate collection and treatment systems, as well as gas extraction wells or vents to safely manage methane and other landfill gases.

Fire Control and Safety: Proper capping, gas venting, and regular monitoring are essential for fire prevention and control, as uncontrolled gas accumulation or exposure of waste can lead to landfill fires.

Recovered Land Utilization: After capping and site restoration, reclaimed landfill sites are often repurposed for parks, green spaces, or public infrastructure, provided that long-term monitoring confirms environmental safety.

3.2.4.4 Methane Mitigation from Bio-mining, Bio-Remediation or Bio-Capping

Bio-mining plays a pivotal role in curbing methane emissions from the waste sector and holds significant potential for carbon reduction. As per estimates from the U.S. Environmental Protection Agency (USEPA), landfills contribute around 12% of global methane emissions, underscoring their role as major methane reservoirs. Given that methane is a highly potent GHG, remediating legacy dumpsites is essential to eliminate this emissions source and support broader climate change mitigation efforts. Taking into consideration methane's higher warming potential than CO_2, studies have estimated that remediating 1 ton of municipal solid waste would be equivalent to 1610 kg CO_2 mitigation. Thus, remediation of dumpsites is essential.

Remediating dumpsites via bio-mining/ bioremediation eliminates the anaerobic conditions that produce methane, essentially preventing future methane generation from legacy waste. These actions also align with Sustainable Development Goal (SDG)13 and the objectives of the Paris Agreement. Furthermore, converting remediated sites into green spaces or forested areas enhances climate benefits by creating carbon sinks that absorb atmospheric CO_2.[13] Additionally, bio-mining projects have a huge potential to reduce methane emissions through the generation of carbon credits (However, very few projects in India are currently generating any carbon credits).

Despite this potential, India lacks comprehensive studies quantifying the GHG reductions achieved through dumpsite remediation. Similarly, there is limited data on the carbon sequestration capacity of green cover developed on reclaimed land. Assessing both the emissions avoided and the carbon sequestered would provide a clearer picture of the net climate contribution of such interventions.

Bringing It All Together

Collectively, bio-mining, bio-remediation, and bio-capping form a comprehensive framework for the safe, scalable, and environmentally sound remediation of legacy dumpsites. The Indian government has actively promoted these strategies under flagship programs like the SBM 2.0, aligning with global goals such as the Sustainable Development Goals (SDG 11, 12, and 13) and India's NDCs. By following this sequence—from excavation to stabilization to final closure—ULBs across India can transform polluting dumpsites into restored land, fostering safer cities and contributing to national sustainability objectives.

3.2.4.5 Challenges Associated with Bio-mining, Bio-Remediation or Bio-Capping:

01 Operational Delays & Capacity Constraints:

Projects often suffer from delays in procurement, lack of skilled operators, and legal hurdles, which slow down remediation timelines. Many sites lack adequate mobile excavation and screening equipment, leading to extended timelines and increased costs.

02 Continuous Waste Inflow:

Even after reclamation begins, fresh waste often continues to be dumped at the site, requiring repeated remediation operations. This is both economically burdensome and labour intensive.

03 Fire Risks & Gas Accumulation:

Legacy dumps accumulate methane, which frequently triggers landfill fires. These incidents complicate remediation efforts and pose safety risks. Bio-capping isolates contaminants but does not eliminate methane or leachate, requiring ongoing gas venting and monitoring.

04 Scale and Complexity of Material Handling:

Excavation generates large volumes of mixed materials that demand sorting, reuse, and proper disposal; mismanagement can result in persistent contamination.

Case Study: Bio-mining Operations at Bhalswa landfill, North-West Delhi

The Bhalswa landfill, located in North-West Delhi, has been a major site for the dumping of mixed municipal solid waste since 1994. Over the years, the dumpsite expanded significantly, reaching an estimated height of 62 metres by 2019 and covering approximately 70 acres (28.3 hectares). By that time, the site had accumulated around 80 lakh cubic metres of legacy waste above ground and an additional 8 lakh cubic metres below ground. In an effort to address the environmental and public health risks posed by this legacy waste, bio-mining operations at Bhalswa were launched on 1 October 2019 under the supervision of the North Delhi Municipal Corporation. This initiative was part of the larger mandate under the SBM 2.0 to scientifically remediate India's major dumpsites.

By 18 August 2020, a total of 6.6 lakh tonnes (661,454 tonnes) of legacy waste had been processed through bio-mining. The recovered material was segregated into various streams for appropriate reuse or disposal. Approximately 85,631 tonnes of inert material were transported to the NTPC Eco Park site at Badarpur and other low-lying areas for use in land levelling and infrastructure work. About 97,075 tonnes of combustible waste, or Refuse-Derived Fuel (RDF), were sent for co-processing—both to cement kilns in Jabalpur and the Waste-to-Energy (WtE) plant at Bawana. The cost of co-processing this RDF was borne by the municipal corporation at a rate of ₹3,240 per tonne for material sent to Jabalpur and ₹1,800 per tonne for material sent to Bawana. In addition, 10,129 tonnes of construction and demolition waste were recovered during the operations.

The bio-mining initiative has led to the clearance of significant portions of the landfill. Approximately 52,700 square metres of waste area with a height of 11 metres was cleared from the first mound, while 6,100 square metres of area with a height of 12 metres was cleared from the second mound. At the time of reporting, around 4,200 metric tonnes of legacy waste were being processed daily. To accelerate the remediation process, the municipal corporation planned to install additional trommel machines to increase the processing capacity to 5,500 tonnes per day. This ongoing remediation effort at Bhalswa is one of Delhi's key examples of how scientific bio-mining can reclaim urban land, reduce environmental hazards, and mitigate methane emissions associated with legacy waste.

3.2.5 Comparative assessment – Landfill Methane Mitigations technologies/ methods

Table 25: Phases of the Biomining process

Parameter	Waste Incineration (WtE)	Biomining	Landfill Gas (LFG) Capture & Utilization	Bio-covers (Methane Oxidation Layers)
Core Principle	Combustion of MSW at high temperature to generate electricity/heat	Excavation of legacy waste, segregation of fractions, treatment of soil-like material, and engineered capping	Extraction of methane through wells and pipes, followed by flaring or energy recovery	Use of compost/ amended soil layers over landfills to biologically oxidize methane
Policy Framework	Recognized under SWM Rules 2026 and promoted in various waste-to-energy policies; often included in urban missions	Explicitly mandated by NGT (2019, 2020, 2024), CPCB guidelines (2019), and SBM-U 2.0 for dumpsite clearance	Supported under MNRE renewable energy programs; limited inclusion in SWM Rules 2026	No direct mention in SWM Rules, CPCB/ NGT orders, or SBM-U frameworks
Financial Model	High CAPEX (~₹150–250 crore/MW); viability gap funding and power purchase agreements required	Very high CAPEX for excavation and processing; costs vary by dumpsite size; funding available under SBM-U 2.0 (300-1200 crore)	High CAPEX for wells, compressors, and flaring/energy units; revenue possible via power generation and carbon credits	Low to moderate CAPEX (compost/ soil procurement, layering); no formal funding schemes yet
OPEX	High (skilled labor, pollution control, ash handling)	Moderate (screening, transport, residual disposal)	Moderate to high (monitoring, maintenance of wells/ pipes, engines)	Low (monitoring, maintenance of cover integrity)
Revenue Streams	Power sales, tipping fees, carbon credits (though uncertain)	Limited: recyclables recovery, land value unlocked	Power sales, carbon credits, renewable energy certificates	None directly; only avoided emissions, possible carbon credit potential
Environmental Impact	Reduces landfill volume but produces toxic ash, dioxins, and requires strict emission control	Reduces legacy dumps, recovers land, lowers fire risk; some residual rejects remain	Reduces direct methane emissions significantly; avoids fires; requires proper design to avoid leaks	Converts methane to CO_2, reducing GHG impact; effectiveness depends on methane flux and cover performance

Parameter	Waste Incineration (WtE)	Biomining	Landfill Gas (LFG) Capture & Utilization	Bio-covers (Methane Oxidation Layers)
Methane Mitigation	Indirect: prevents new waste methane, but incineration itself emits CO_2	Indirect: by eliminating dumps, reduces methane from old waste	Direct capture and destruction/utilization of methane	Direct oxidation of methane to CO_2 in cover soils
Case Studies	Okhla WtE (Delhi), Jindal ITF (Hyderabad), faced feedstock and emission controversies	Indore, Varanasi, Bangalore: successful biomining with land recovery	Gorai (Mumbai) CDM project; Ghazipur LFG project (Limited success)	IIT Madras/IIT Delhi research pilots; international success in Sweden, Canada
Technical Challenges	Segregation requirement unmet; high moisture reduces calorific value; public opposition	Large land requirement for processing; rejects disposal; odor and dust during excavation	Old dumps have heterogeneous waste; leachate infiltration hampers capture efficiency	Effectiveness declines if methane flux too high or cover dries/ cracks
Regulatory Drivers	MoEFCC, MNRE, NITI Aayog push for energy recovery	NGT orders (Hyderabad, Indore, Delhi), SBM-U mandate	MNRE renewable energy targets; CDM/ VCM protocols	None yet; may align with future methane commitments
Health/Safety Concerns	Emissions (SOx, NOx, dioxins, heavy metals); ash disposal	Worker exposure during excavation; landfill fire risk	Explosion risk if gas accumulates; operational hazards in engines	Minimal if well-maintained; dust/odor during installation
Public Perception	Generally negative (NIMBY issues, emission fears)	Largely positive (visible dumpsite clearance, land recovery)	Neutral to positive where energy recovery visible	Neutral (largely unknown to communities)
Land Use Outcomes	Reduces landfill growth but plants need land	Recovers large tracts for reuse (parks, housing)	Landfill remains but stabilized with reduced risk	Landfill remains capped; not reusable in short term
Timeframe for Results	Medium-term: 2–4 years to construct and stabilize operations	Medium-term: 3–5 years for large dumpsites	Medium-term: 2–3 years to set up; results visible in flaring/power over next 8-10 years	Short-term: within 6–12 months of cover installation
Policy Incentives	Power purchase agreements, renewable energy certificates	SBM-U 2.0 grants, state-level funds	MNRE subsidies, carbon credits	Currently none
Circular Economy Linkage	Energy recovery but low material recovery. Operates agaisnt the CE framework	High material recovery (recyclables, soil for landscaping). Operates In line with CE framework.	Energy recovery only; no material recovery	No material recovery; only GHG reduction Operates against the CE framework
Global Alignment	Mirrors EU/Japan WtE models, but with stricter segregation	Follows global remediation practices (US, EU)	Consistent with international LFG-to-energy models	Mirrors EU/US bio-cover pilots, not yet mainstream
Legal Precedent	Recognized but contested in courts (pollution concerns)	Strongest legal mandate (NGT binding orders)	Legally permissible but not mandated	No precedent in Indian law

3.2.6 Technology Assessment for the Indian context.

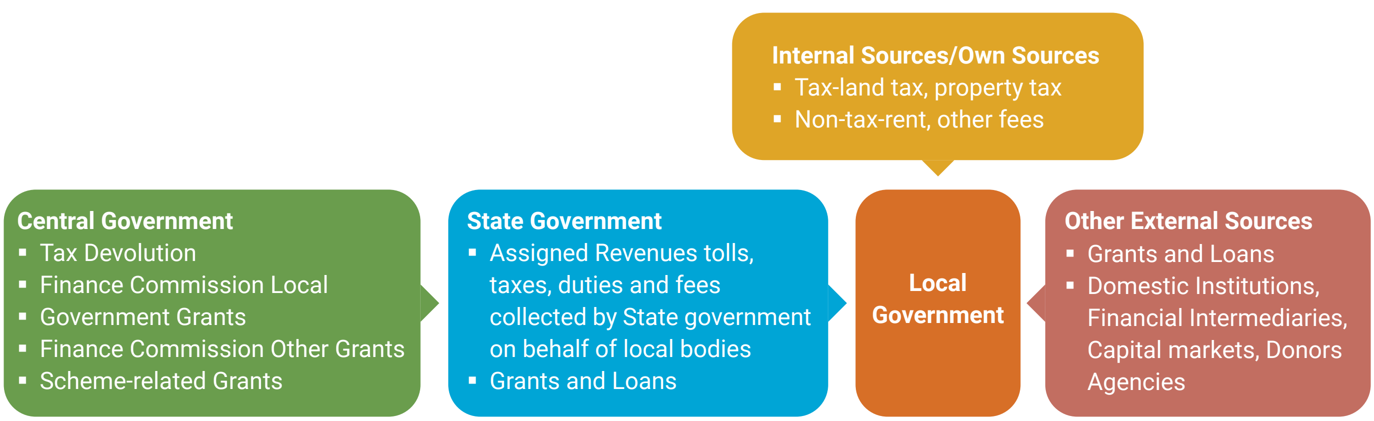
Table 26: Technology assessment for the Indian context

Technology	Cons / Limitations	Overall Conclusion / Rationale
Waste-to-Energy (WtE / Incineration)	▪ Poor alignment with circular economy principles; destroys recoverable material value. ▪ Consistently underperforms due to low-calorific waste and poor segregation. ▪ Generates toxic ash, dioxins, requires stringent emission controls. ▪ Repeated financial and operational failures; strong public opposition.	Least preferred option. Despite policy push, WtE has proven unreliable in Indian conditions and undermines material recovery. Should remain marginal, used only in exceptional cases (dense metros with strict oversight/regulatory compliances).
Biomining + Bio-capping	▪ Large land and time requirements. ▪ Recovered rejects still need safe disposal. - ▪ Operational challenges (dust, odor, safety risks).	Most CE-aligned and policy-backed approach. Actively mandated by NGT SBM-U 2.0 and SWM rules 2026. Proven success in Indian cities (e.g., Indore). Should remain the primary national strategy for dumpsite remediation.
Landfill Gas (LFG) Capture & Utilization	▪ Viable only at engineered landfills with high organic content. ▪ Limited Indian pilots; mixed outcomes (e.g., Ghazipur — failed due to funding). - ▪ High CAPEX and O&M costs. ▪ Weak regulatory mandate, voluntary adoption.	Promising but conditional. Can deliver methane mitigation at select engineered sites but requires stronger government funding and regulatory backing. Not scalable across thousands of open dumps.
Bio-covers (Methane Oxidation Layers)	▪ Not recognized in SWM Rules, SBM-U, or NGT guidelines. ▪ No material recovery; only end-of-pipe emission control. ▪ Needs specific soil/compost mixtures, regular upkeep. ▪ Only academic pilots in India; no municipal scale adoption.	Supplementary option. Feasible as a low-cost passive measure for small or legacy dumps, but cannot replace core remediation methods. Needs policy recognition and standards before scaling.

3.3 Financing Landfill Management

3.3.1 Current Status

The flow of financing for municipal bodies (Figure 1.) starts with the central government providing funds to the state governments through tax devolution, finance commission grants, and scheme-related transfers. The state government then allocates funds to ULBs for carrying out their various activities. Apart from the government funds, ULBs also have their own internal revenue generation sources through various tax regimes and user fees along with grants or loans from domestic institutions, capital markets, and international donor agencies. Expenditure on waste management on a per capita level range on average from INR 50-250, with larger cities seeing higher expenditure – INR 295 in Chennai, INR 431 in Delhi, and INR 428 in Mumbai. As per one CPHEEO report, ULBs spend around a cost of approximately Rs. 500 to Rs. 1,500 per ton for solid waste management, covering collection, transportation, treatment, and disposal.



Despite a multi-tiered financial support system for solid waste management (SWM) in India, local governments continue to face significant challenges in both the allocation and utilization of funds. On average, Urban Local Bodies (ULBs) can cover only about half of the necessary expenses for SWM, with the share of a ULB's budget allocated to SWM ranging from 5% to 40%. In some smaller towns, where waste management is a primary focus, allocations can reach up to 70%. In India the financing of SWM, even with clear policies in place and various funding options available, is **highly impacted by insufficient and inconsistent budget allocations, both regionally and throughout the SWM process.** The situation is made worse by **delays in releasing funds, underutilization of available grants, and priority funding on collection and transportation instead of processing and proper disposal.**

At the national level, the **Government of India's Budget** for FY 2025-26 allocated ₹5,000 crore for SBM-Urban (9.3% of the Ministry of Housing and Urban Affairs budget) and ₹7,192 crore for SBM-Grameen (9.6% of the Ministry of Jal Shakti budget), indicating that around **10% of the budget allocation for urban and rural management is directed towards SWM.**[9] However, this **allocation is far from uniform across the country,** with notable variations between states and even among ULBs within the same state and a **significant portion of funds either underutilized or delayed** due to **cumbersome procedures, lack of project readiness, and administrative bottlenecks.**

Moreover, the distribution of funds across the different stages of SWM is highly uneven. Typically, **50–70% of total SWM expenditure is devoted to street sweeping and waste collection, 20–30% to transportation, and less than 5% to processing and final disposal.** This heavy emphasis on collection and transportation comes at the expense of scientific processing and safe disposal, which are essential for long-term sustainability. Ideally, **a greater share of funding should be directed towards strategic segregation, processing and scientific disposal, but in practice, these areas receive minimal investment.**[291]

Certain sub-national cases are noted below:

Kerala: In June 2016, the Government issued orders for a mandatory allocation of 10% of the Development Fund (General) for waste management activities. This was revised in April 2017, directing local bodies to allocate 15% of the Development Fund (General) to Haritha Keralam Mission projects, with priority to waste management. By February 2018, ULBs were further instructed to allocate 20% of the Development Fund (General) for LIFE Mission projects and at least 15% of the remaining fund for Haritha Keralam Mission projects focusing on waste management and water conservation.5 Despite clear government directives, actual waste management expenditure by Kerala's ULBs from 2016 to 2021 remained extremely low. Against the mandatory utilisation of 10-15 per cent of development funds towards solid waste management in the state, test-checked ULBs during the performance audit under CAG highlighted that the state only utilised 0.48-1.66 per cent for waste management. The number of ULBs with zero allocation of Development fund (General) towards SWM ranged from one to six each year. This consistent underutilisation underscores a **reluctance among ULBs to initiate new waste management projects,** even when funds were available and mandated.[292]

Maharashtra: Between 2016-17 and 2021-22, the total SWM expenditure in 45 test-checked ULBs during the performance audit by CAG, it was found that out of the ₹18,732 crore utilized by the ULBs, of which ₹16,148 crore (86%) was incurred towards revenue expenditure for day-to-day operations such as collection and transportation, while **only ₹2,584 crore (14%) was spent on capital expenditure for infrastructure and equipment.** Furthermore, a significant portion of allocated capital grants remained unspent due to incomplete procurement, civil works, and issues such as non-availability of land.[293]

Haryana: The budget allocation for FY 2023-24 was around Rs. 61.25 crores out of which 45 crore (~74%) were allocated for payment for door-to-door collection, transportation and processing of daily generated MSW. As per their expenditure heads, the **budget allocated was not enough** for these operations as their expenditure in the given financial year exceeded the allocated budget of Rs. 45 crores and reached Rs. 47 crores.[294]

Jharkhand: In the audit of CAG, expenditure on SWM ranged between just 2% and 11% of total expenditure during 2017-22 across various ULBs. There was **no expenditure on SWM activities in 13 and six ULBs**

from the 14th and 15th Finance Commission grants, respectively, despite the availability of funds. The Department attributed this to the expectation that capital expenditure would be funded from central and state shares under the Swachh Bharat Mission, but the end result was that a **large share of funds allocated for SWM remained unspent,** with the unspent amount ranging from 74% to 100% across the ULBs during the period.

These cases underscore an urgent need for more reliable and sufficient budget allocations, better fund utilization, timely disbursement, and increased investment in sustainable waste management infrastructure. Effective financing instruments and improving budget expenditure tracking could also help close resource gaps and promote more effective and sustainable SWM solutions across the nation.

To bridge financing gaps and quality of provision of solid waste management services, India has tried bringing in Public Private Partnerships (PPP) for various activities within waste management and this option remain underutilized.

3.3.2 Financing Structures

3.3.2.1 Public-Private Partnerships

Engaging the private sector in delivering solid waste management services can yield significant benefits when structured effectively. Such partnerships can be integrated across multiple stages of waste management, including segregation at source, door-to-door collection, transportation, treatment, and scientific disposal. **Through Public Private Partnership (PPP) models, urban local bodies can harness private sector expertise, innovation, and resources to navigate operational challenges of waste management.**[295] These collaborations can help bridge existing infrastructure and capacity gaps, leading to enhanced service delivery. Mechanisms like long-term contracts, assured waste supply agreements, preferential land lease terms, and structured payment models (e.g., tipping fees) can further attract private investment. Additionally, enabling regulatory frameworks and enforcement of municipal bye-laws are critical to institutionalise and facilitate private sector participation. Table 1 highlights the key benefits of Public-Private Partnerships for waste management.

Table 27: Key Benefits of Public-Private Partnerships for Waste Management

Key Benefit	Description
Improved Efficiency and Service Delivery	Private-sector involvement enhances collection, transport, and processing through tech and efficient management. Examples: Indore and Navi Mumbai's improved cleanliness rankings.
Increased Investment and Financial Sustainability	Attracts private investment, reducing municipal burden. Example: Indore Bio-CNG Plant converts organic waste into fuel and generates revenue.
Waste-to-Energy and Circular Economy Development	Facilitates WtE plants in Delhi, Hyderabad, Pune. Promotes plastic/e-waste recycling, aiding circular economy.
Enhanced Technological Integration	Brings in smart systems like AI waste sorting, GPS tracking. Cities like Bhopal and Surat use RFID for efficiency.
Better Compliance with Environmental Regulations	Supports compliance with SWM Rules (2026) & PWM Rules (2018) via scientific waste handling. Example: MRFs in Bengaluru, Chennai.
Job Creation and Formalization of the Informal Waste Sector	Integrates informal waste pickers into formal systems, improving livelihoods. Example: SWaCH cooperative in Pune employs over 3,000.
Reduction in Landfill Dependency and Environmental Impact	Decentralized models in Ambikapur, Mysuru reduce landfill use by 60-80%. Private composting reduces methane emissions and supports agriculture.

While PPPs offer major advantages for urban local bodies, **they are equally attractive to private sector partners** for several reasons. The expanding urban waste sector in India presents significant growth opportunities, allowing private firms to access new markets and scale operations. Engagement of private players through government facilitation, such as land provision and regulatory support, lowers entry barriers and streamlines project implementation. **PPPs additionally encourage the deployment of innovative technologies that improve efficiency and environmental outcomes.** Participation in such projects also aligns with global Environmental, Social, and Governance (ESG) goals, boosting corporate reputation and investor confidence.

One of the **primary challenges faced in public-private partnership (PPP) projects is the complexity and delay associated with obtaining statutory approvals.** Bureaucratic hurdles leading to project delays and cost overruns are the most common risks in PPP implementation. Certain examples are:

Slow Approval and Tendering Processes: Bureaucratic delays in project approvals and tendering are major bottlenecks in landfill remediation and waste processing.

Environmental Clearances: Obtaining environmental clearance for Waste-to-Energy (WTE) plants or biomining projects takes 18–24 months on average, compared to the mandated 6-month timeline. For example, the Okhla WTE plant in Delhi faced a 3-year delay due to litigation and clearance hurdles.

Land Allocation Challenges: In Mumbai, the Deonar landfill remediation project stalled for 2 years due to disputes over land ownership between the BMC and the Maharashtra government.

Tendering Corruption: A 2022 CAG audit revealed that 40% of SWM tenders in Uttar Pradesh were awarded to ineligible contractors, leading to substandard work and project delays.

A proactive solution involves the public authority, acting as the project owner—assuming responsibility for securing all necessary clearances before the bidding stage. By frontloading the approval process, the government can substantially de-risk the project. This not only streamlines execution but also provides greater clarity and confidence to potential private partners, thereby attracting higher-quality bids and fostering broader participation. Additionally, pre-obtained approvals enable bidders to better estimate project risks, develop more precise financial and technical proposals, and allocate resources efficiently. Ultimately, early regulatory facilitation signals the government's commitment to a supportive PPP environment and plays a key role in reducing time and cost escalations.

Beyond regulatory issues, additional challenges also commonly hamper PPP models in solid waste management:

There is often strong resistance from labour unions, particularly concerning the integration and utilisation of existing municipal manpower when private players are brought in.16 This leads to operational friction and delays in project rollout.

Private entities face difficulties in securing reliable markets and pricing mechanisms for by-products such as electricity, biogas, RDF, and compost.17 The absence of assured offtake agreements or stable demand for these products undermines financial viability and investor confidence. Therefore, overcoming institutional resistance and establishing market linkages for waste-derived products are equally critical to the success of PPP initiatives in the sector.

Case Study: ITC's Public-Private-People Partnership for Solid Waste Management in Saharanpur[296]

The city of Saharanpur in Uttar Pradesh saw an innovative intervention in 2006 when ITC Limited launched a pilot project in collaboration with Muskan Jyoti Samiti (an NGO), the Saharanpur Municipal Corporation (SMC), and district authorities. Designed as a decentralized Public-Private-People Partnership (4P), the model aimed to address mounting waste management challenges while simultaneously generating sustainable livelihoods for marginalized waste workers.

Unlike conventional municipal approaches that relied heavily on communal bins and unsegregated disposal, the ITC-led initiative introduced a door-to-door collection system. Waste collectors, organized into cooperatives and trained by the NGO partner, used hand-pulled carts equipped with separate compartments for dry and wet waste. The model promoted primary segregation at the household level through sustained awareness campaigns involving posters, street plays, and community engagement. Collected waste was taken to decentralized processing units—located on land provided by the municipality, where it was further sorted. Organic waste was composted in open aerobic brick structures, while recyclables were sold to vendors, and only a small fraction of non-recyclables was sent to landfills.

Over a decade, the program expanded to cover over 18,000 households across 30 wards, with over 90% of waste diverted from landfills, far surpassing the Ministry of Urban Development's 80% benchmark. Compost production exceeded 350 MT annually and was sold to nurseries and local buyers, while recyclable sales and user fees contributed to revenue. Between 2012 and 2015, the average cost recovery stood at 70%, with user charges accounting for nearly half of the revenue. Notably, the fee collection rate exceeded 91%, far outperforming national averages. ITC continued to fill the remaining financial gap while strengthening the cooperative's managerial capacity.

Stakeholder engagement formed the backbone of the model. While the municipal corporation transitioned to a facilitative role, residents participated through informal ward committees, promoting accountability and behaviour change. Waste workers not only gained dignified employment but also became co-managers of the system. An annual multi-stakeholder forum provided a space for shared learning and strategic planning.

Case Study: Indore PPP Waste Management Model[297]

Indore's transformation into India's cleanest city is a leading example of a successful Public-Private Partnership (PPP) in solid waste management. Beginning in 2016, the Indore Municipal Corporation (IMC) collaborated with private partners to overhaul its waste management system, introducing 100% door-to-door collection and strict waste segregation at source. The city invested in modern infrastructure, including partitioned collection vehicles and advanced processing facilities operated under the PPP model. Central to the PPP was the GOBARdhan bio-CNG plant, launched under the national waste-to-wealth initiative. This flagship facility, built on a 20 year BOOT/PPP model (costing ₹150 crore, with ₹10 crore viability gap funding), processes up to 550 TPD of segregated wet waste, producing around 17 tonnes/day of bio-CNG, 100 tonnes of compost daily, and liquid fertilizer. Under the PPP contract, IMC committed to purchasing at least half of its bio-CNG output—used to fuel city buses and sold through Avantika Gas—boosting sustainability while securing cleaner transportation. The IMC garners annual revenues including ₹2.52 crore in land premium, ₹1.43 crore from dry-waste royalties, and carbon credit earnings totalling around ₹9 crore over two years.

Over 90% of households now segregate waste, and the city's waste processing facility manages 1,000 metric tons daily with a 95% recovery rate, drastically reducing landfill use and environmental impact. The IMC's approach combined strong leadership, citizen engagement, regular monitoring, and financial innovation, resulting in high efficiency, cleaner surroundings, and sustainable resource recovery, making Indore a model for urban waste management in India.

3.3.2.2 Public Procurement

India's public procurement system, comprising approximately 20–22% of the national GDP, is a powerful tool to deliver public infrastructure and services, including in sectors such as waste management. Governed by the General Financial Rules (GFR) 2017, it standardizes procurement procedures across ministries and promotes e-procurement and competitive bidding. However, the system's default preference for awarding contracts to the lowest-cost bidder under the L1 method has long inhibited the uptake of innovative and sustainable technologies.

In the waste management sector, this emphasis on upfront cost minimization has serious implications. Urban Local Bodies (ULBs), often constrained by limited budgets, default to low-cost, basic solutions such as manual waste collection and unsanitary landfilling. These practices persist despite the availability of technically superior and environmentally beneficial alternatives like waste-to-energy plants, biomethanation units, and material recovery facilities. The procurement system's inability to value long-term savings, lifecycle benefits, and environmental performance leads to inefficient service delivery and prevents the sector from contributing meaningfully to climate goals and the circular economy.

Recognizing these limitations, the Government of India has introduced reforms to shift from a cost-centric approach to a value-based procurement model. In 2021, the Department of Expenditure issued guidelines promoting the use of Quality-cum-Cost Based Selection (QCBS) for works and non-consultancy services, not just consultancy—as a more balanced procurement approach. QCBS allows for the assessment of both technical quality and cost through weighted scoring, enabling agencies to select bids that offer long-term value.

This reform has begun to show results. For example, under the World Bank-supported Kerala Solid Waste Management Project, tenders were evaluated using QCBS. The winning bidder quoted ₹3.2 crore, significantly higher than a competing bid of ₹1.9 crore, but was selected due to superior technical qualifications. This shift prioritizes quality outcomes in public service delivery, even if it comes at a higher initial cost. However, QCBS implementation remains uneven. Many agencies continue to default to L1 due to limited training, lack of clear operational guidance, and concerns around subjective technical scoring.

To further embed sustainability into procurement, initiatives like the Task Force on Sustainable Public Procurement and the integration of green filters into the Government e-Marketplace (GeM) are underway. These aim to support the adoption of environmental and social criteria in public contracting. Still, these tools remain underutilized in the waste sector.

Transforming India's procurement culture to support high-impact, low-emission waste systems will require not only regulatory reform, but also capacity building across procurement entities, standardization of quality-based tendering frameworks, and strong political support. Public procurement—when designed with quality and sustainability in mind—can become a key enabler in addressing India's mounting waste and climate challenges.

3.3.3 Innovative Financing Instruments

Table 28: Comparison of innovative financing instruments for landfill management

Instrument	Funding Mechanism	Primary Objective	Risk Distribution	Monitoring & Verification Needs	Scalability Potential
Performance-Based Grants (PBGs)	Intergovernmental transfers released upon achievement of service benchmarks	Incentivize local bodies for measurable service improvements	Government bears financial risk; performance risk on recipient	High – periodic review of municipal performance indicators	High – replicable in state/national schemes
Program for Results (PforR)	Loan disbursements based on fulfillment of Disbursement-Linked Indicators (DLIs)	Strengthen institutional capacity and promote results-oriented delivery	Shared risk; funding contingent on performance, but systems-led	Very High – independent verification of DLIs critical	High – suitable for multi-sector programs across cities
Output-Based Aid (OBA)	Subsidies disbursed upon independent verification of service delivery outcomes	Expand access to services for the poor while ensuring accountability	High performance risk on recipient; donor-funded support helps	Very High – intensive third-party verification of outputs	Medium – best suited for targeted service expansion
Municipal Green Bonds	Capital raised via debt instruments specifically for green infrastructure projects	Enable climate-aligned capital investments by urban local bodies	Market-linked; risk on issuer's credit and project pipeline	Medium – post-issuance green audits by third parties	Medium – depends on investor appetite and creditworthiness
Carbon Financing	Tradable credits under compliance/ voluntary market linked to verified emission cuts	Create market incentives to reduce methane and GHG emissions	Market and performance risk; rewards tied to emission reduction	Very High – requires rigorous MRV protocols for carbon markets	High – demand-driven; viable for capital-intensive projects high potential under upcoming Indian carbon market
CSR Funding	Corporate funds directed to social/ environmental causes via mandatory CSR obligation	Promote decentralized waste systems and social inclusion	Low risk; flexible, but limited scale and accountability	Low – basic documentation required; internal reporting	Medium – community/local-level scale; not suitable for infra
EPC with O&M Model	Publicly funded construction + performance-based O&M payment model	Ensure quality infra delivery + long-term operational accountability	Govt holds capital risk; contractor accountable for delivery and uptime	Medium – performance standards linked to O&M contracts	High – replicable in urban infra with O&M needs
Hybrid Annuity Mode (HAM)	Split funding: 40% upfront govt funding; 60% repaid via annuities	Attract private capital and balance construction and operational risk	Balanced; annuities ensure steady returns tied to performance	High – requires operational audits and service output tracking	High – expanding use in urban infra; complex to structure

3.3.3.1 Results-Based Financing (RBF)

Results-Based Financing (RBF) in Solid Waste Management (SWM) refers to financing mechanisms where funds are disbursed based on the achievement of predefined performance results, rather than just inputs. These projects can vary by technical scope—either focused solely on SWM or integrated into broader urban development—and by scale, ranging from small pilot components to full-scale national programs. RBF can be used as a tool to boost community involvement in waste management efforts. For instance, local groups can be motivated with rewards to come together and adopt positive habits of waste segregation, recycling, and keeping their neighbourhoods clean. This not only helps in managing waste more effectively but also fosters a sense of ownership and responsibility within the community.

Common RBF instruments that can be employed in the country include:

- **Performance-Based Grants (PBGs)**

  Performance-based grants entail fiscal transfers from higher government tiers to local governments, conditional on meeting specific performance targets. PBGs help incentivise improvements in governance, transparency, and service delivery while encouraging local innovation. These have shown strong results in boosting institutional capacity and own-source revenues.

Case Study: Million-Plus Cities Challenge Fund (MCF) - 15th Finance Commission [37] [38]

One notable Indian example is the Million-Plus Cities Challenge Fund (MCF) recommended by the 15th Finance Commission. The MCF is a performance-based grant mechanism that allocates funds to cities with over 1 million population only upon achieving specified service improvements in sectors including solid waste management. The Commission earmarked ₹26,057 crore under the MCF specifically for urban water supply, sanitation, and SWM service-level benchmarks. To earn these grants, cities are evaluated on key indicators such as: door-to-door waste collection coverage, waste segregation at source, percent of municipal solid waste scientifically processed, and progress toward achieving "garbage-free city" star ratings set by MoHUA. Top-performing cities receive a larger share of the grant, creating a healthy competition. The overall objective of this entire engagement has been to incentivize urban local bodies to prioritize SWM improvements and sustain outcomes through financial rewards.

- **Program for Results (PforR)**

  Program for Results (PforR) is a World Bank financing instrument that links disbursements directly to the achievement of agreed Disbursement-Linked Indicators (DLIs). Unlike traditional project financing, PforR relies on the borrower's existing institutions and systems for implementation. Some urban PforRs include SWM-specific DLIs. The model aligns well with sectoral reforms by promoting institutional strengthening, capacity building, and outcome-driven delivery.

Case Study: Chennai City Partnership [39] [40] [41]

India has also applied the World Bank's Program-for-Results financing to urban services including SWM. A prime case is the Chennai City Partnership: Sustainable Urban Services Program (2021–present) – a PforR initiative co-funded by the World Bank and AIIB. Under this program, loan disbursements are tied to the achievement of institutional reforms and service delivery targets in multiple sectors such as water supply, public transport, public health, and solid waste management. In the SWM vertical, Chennai's city government (Greater Chennai Corporation) must implement a set of result-driven actions to draw down funds. These actions include establishing an IT-enabled performance monitoring system for waste collection, developing a comprehensive SWM Master Plan and investment strategy, instituting an O&M financing plan to make waste services financially sustainable, and building capacity through training and community outreach. The program also supports capital investments like new Material Recovery Facilities (for recycling) in line with these plans. As funds are released only upon independent verification of these targets, the city has been motivated to strengthen its waste management institutions. Early results include better data tracking of garbage collection, initiation of waste-reduction programs and planning for higher treatment capacity.

- **Output Based Aid (OBA)** OBA is a result-based financing tool to provide subsidies based on performance to deliver essential services to economically disadvantaged groups. This approach supports service expansion in informal settlements or slums, where conventional models often face viability challenges. It ensures that subsidies directly benefit the target population and align with equity-oriented goals in urban service delivery.

Nepal's Results-Based Financing for Waste Management

In 2012, Nepal, supported by the World Bank, launched a pioneering **results-based financing (RBF) initiative for municipal solid waste management (SWM).** This program linked funding directly to independently verified performance outcomes, incentivizing municipalities to improve services.

Eligibility required existing landfills, basic collection systems, and fee collection capacity. Municipalities also developed four-year SWM improvement plans, including environmental and social management.

The core was a **results-based subsidy mechanism:** funds were disbursed over four years only when specific **technical performance indicators** were met, ensuring public money was tied to measurable service enhancements. Strong **environmental and social safeguards** were integrated, guiding risk management and protecting vulnerable groups like informal waste pickers, who were formally included.

The project demonstrated how RBF can effectively drive urban service delivery in developing countries, fostering municipal ownership and integrating crucial social and environmental accountability.

- **Municipal Green Bonds**

  A significant financing tool that local governments use to raise capital specifically for environmentally sustainable urban infrastructure projects, such as renewable energy, clean transportation, water management, and waste recycling. These bonds function like traditional municipal bonds but are distinguished by their proceeds being exclusively allocated to green projects, thereby supporting cities in meeting their sustainability and climate resilience goals. The Securities and Exchange Board of India (SEBI) regulates their issuance.[298]

Case Study: Pimpri Chinchwad Municipal Corporation (PCMC) Municipal Green Bond[299]

In June 2025, Pimpri Chinchwad Municipal Corporation (PCMC) successfully raised ₹200 crore through the issuance of green municipal bonds, becoming the first civic body in Maharashtra to do so. Rated AA+ (Stable) by CRISIL and CARE,the five-year bonds carry a competitive coupon of 7.85%, secured through a bond of property tax collections to ensure timely servicing. This green bond issuance follows PCMC's earlier ₹200 crore municipal bond in 2023, underscoring the corporation's growing commitment to sustainable urban infrastructure financing. Overall, PCMC's green municipal bond represents a pioneering financing model in India's urban local bodies, leveraging capital markets to fund climate-friendly projects like green infrastructure, which can be replicable across sectors including waste management.

The Kerala Solid Waste Management Project, approved in 2021 with a funding of US$105 million, exemplifies a results-based financing (RBF) approach dedicated to advancing the solid waste management (SWM) sector in India. This project seeks to strengthen solid waste infrastructure, expand service coverage, and improve environmental outcomes by tying financial disbursements to the achievement and independent verification of specific, pre-agreed performance indicators. Payments to municipalities and service providers are contingent upon measurable results, such as expanding waste collection coverage, increasing the volume of waste processed and scientifically disposed of, improving user fee collection rates, and reducing unregulated dumping and open burning. The project brings together multiple stakeholders: the World Bank supplies funding and technical support, the state government and urban local bodies (ULBs) are responsible for implementation, and an Independent Verification Agent (IVA) ensures that reported results are verified before any disbursement of funds. Grants are released to ULBs and service providers only after independent verification of achieved targets, thereby incentivizing local authorities to prioritize SWM in their budgeting, enforce fee collection, and uphold operational standards.

- **Carbon Financing**

  Carbon finance is another key financing instrument that supports solid waste management (SWM) by providing financial incentives for GHG emission reductions. Through registries such as VERRA (for voluntary markets) or the UNFCCC's CDM (for compliance markets), SWM projects that mitigate methane and other GHG emissions can generate tradable carbon credits, offering a supplementary revenue stream. Projects that qualify under recognised carbon methodologies can generate carbon credits such as Verified Carbon Units (VCUs) or Certified Emission Reductions (CERs) based on the volume of emissions avoided. Some of the key methodologies include ACM0001 (Flaring or use of landfill gas), AMS-III.G (Landfill methane recovery), and AM0025 ver. 6 (avoided emissions from organic waste through alternative waste treatment processes).

  In some cases, these credits have helped recover a significant percentage of capital costs, making them especially valuable for capital-intensive waste-to-energy or landfill gas capture projects. The ability to access carbon finance can significantly enhance the financial viability of SWM projects, particularly in urban local bodies (ULBs) facing fiscal constraints.

  SWM projects can generate Certified Emission Reductions (CERs) or Verified Carbon Units (VCUs) by reducing methane and other emissions, with potential to recover up to 50% of capital costs through carbon credit sales.47 This makes it especially valuable for capital-intensive waste-to-energy or landfill gas capture projects.

Carbon markets exist as:

- **Compliance Markets:** Legally enforceable, often using cap-and-trade systems, where firms that exceed emission limits must buy credits from those with surplus.
- **Voluntary Markets:** Firms choose to offset emissions without legal obligation.

  In India, efficient SWM could help companies earn credits, while also encouraging greater environmental compliance and creating revenue opportunities, thus reinforcing sustainability through a market-based approach. Projects such as waste-to-energy facilities, biomethanation plants, composting units, and landfill remediation can contribute to national climate goals while generating marketable carbon credits. For instance, integrated WtE projects that avoid landfill methane emissions and displace fossil-derived electricity can access substantial credit volumes, as demonstrated by the Timarpur-Okhla WtE plant in Delhi.

Case Study: Carbon Financing for Timarpur-Okhla Waste-to-Energy Project

The Timarpur-Okhla Waste Management Company Pvt. Ltd. (TOWMCL) project is an integrated municipal solid waste (MSW) processing and waste-to-energy (WtE) facility in Okhla, Delhi. The plant is designed to intake approximately 2,050 tons per day (TPD) of MSW and generate about 20.9 MW of electricity using a refuse-derived fuel (RDF) combustion technology. This represented an upscale from the initial plan of 16 MW capacity, achieved by adopting improved technology and consolidating operations at a single site (Okhla) rather than two separate locations. At about 90% plant load factor (335 operating days/year), the facility produces an estimated 151.23 GWh of gross electricity annually. The WtE facility uses a comprehensive waste segregation and RDF production process. The Municipal Corporation of Delhi supplies the raw MSW to the plant. The plant employs state-of-the-art boiler technology for efficient combustion of RDF, with a large pre-drying zone in the furnace that allows moist waste to be burned without external drying. A high-efficiency steam turbine converts the heat to electricity. The incoming MSW is processed to recover recyclables and remove inerts prior to combustion. This includes manual sorting, magnetic separation for metals, and trommel screening to remove fine inert matter. Recovered metals and other recyclables are diverted to recycling streams, while organic combustibles become RDF, improving overall resource recovery and reducing landfill burden.

The project was formulated under the Clean Development Mechanism (CDM) to earn carbon credits by mitigating GHG emissions. The approved methodology AM0025 (Version 06), "Avoided emissions from organic waste through alternative waste treatment processes", has been applied to quantify these benefits. The project estimated an average annual GHG emissions reduction of 308,262 tCO_2e per year. The Timarpur-Okhla project was officially registered as a CDM project on 10 November 2007. The project participants include TOWMCL (the project proponent/SPV in India) and an Australian entity, WeAct Pty Ltd, as an authorized participant. Throughout the crediting period, the project underwent periodic monitoring and verification to issue CERs based on actual performance. The first monitoring period (Mar 2011 – Aug 2012) yielded an issuance of 12,478 CERs. At the end of six monitoring periods (2011-2019), the project yielded an issuance of 4,57,385 CERs. Each CER represents one tons of CO_2-equivalent mitigated, and these credits can be sold or used to meet emission targets. The Timarpur-Okhla CERs have been made available both for compliance buyers and on the voluntary market.

Motivation to Reduce landfill Methane in the Upcoming Indian Carbon Market

India's net-zero trajectory and commitments under the Paris Agreement led the Bureau of Energy Efficiency (BEE) to introduce the Indian Carbon Market (ICM). Building on past energy efficiency schemes and voluntary carbon mechanisms, the new ICM aims to mobilize climate action across both mandatory and voluntary dimensions, operating through a government-administered electronic platform, known as the Carbon Credit Trading Scheme (CCTS).51 Eight methodologies under Offset Mechanism have been approved by the Central Government in March 2025, including methodologies for renewable energy (including Hydro and Pumped storage), green hydrogen production, industrial energy efficiency and landfill methane recovery.52 Specific to the scope of waste management, two methodologies have been included:

BM WA03.001 Methodology for Landfill Methane Recovery

The BM WA03.001 methodology governs the recovery of methane from landfills through its capture and subsequent combustion, aimed at reducing emissions of this potent GHG. It is adapted from the AMS-III.G methodology (version from 14 July 2019). This methodology applies to landfill sites used for the disposal of municipal, industrial, or other solid waste that contains biodegradable organic matter. Projects under this methodology are required to demonstrate that they do not increase the amount of methane generated by altering waste management practices, such as adding liquids or introducing bacteria to accelerate anaerobic degradation. The methodology is applicable only if the project does not interfere with existing organic waste recycling. Depending on whether the captured landfill gas (LFG) is flared or used for energy, the project must apply sectoral scopes accordingly—waste handling and disposal (Scope 03) alone for flaring, or both Scope 03 and energy (Scope 01) if the gas is used for power or heat generation.

BM WA03.002 Methodology for Flaring or Use of Landfill Gas

BM WA03.002 expands the scope to include a wide range of landfill gas applications—flaring, power generation, heat production, or supplying gas through pipelines and trucks. It is based on the ACM0001 methodology (version from 14 June 2019). This methodology is designed for both greenfield and existing landfills. It supports new installations of LFG capture systems, or enhancements to existing ones, as long as they lead to increased recovery or expanded utilization of the gas. It also explicitly prohibits project designs that deliberately alter landfill conditions to boost methane production. The project boundary includes not only the landfill site and gas processing units but also auxiliary equipment such as power plants, boilers, or gas distribution systems. Emissions from flaring, power or heat generation, gas transport, and fossil fuel use are comprehensively accounted for.

3.3.3.2 CSR Funding

The Section 135 of the Companies Act, 2013 mandates businesses to spend 2% of their profits for CSR, which can be harnessed towards solid waste management initiatives.[300] The CSR funding can be utilised for localised waste processing facilities in a decentralised waste management system which involves setting up small-scale composting hubs and recycling hubs within communities. The CSR funding can also be utilised by the ULBs to creating awareness among the communities for waste segregation, training the informal sector for effective collection and storage. The CSR funding can also be used to leverage technology for enhancing the transparency and efficiency through geotagging and automated reporting procedures in solid waste management procedures.

3.3.3.3 EPC with O&M Model

The Engineering, Procurement, and Construction (EPC) with Operations & Maintenance (O&M) model is a project delivery approach where a contractor is responsible for designing, constructing, and commissioning a solid waste management facility, followed by its operation and maintenance for a specified period. In this model, the government or urban local body (ULB) finances the project and retains ownership of the assets. The private contractor is selected through a competitive bidding process and is accountable for delivering the project on time and within budget, as well as ensuring efficient operation and maintenance post-construction. The O&M phase typically lasts several years, during which the contractor is paid a fixed fee or performance-based payments for maintaining service standards. This model helps leverage private sector expertise in operations while minimizing financial risks for the private partner, as the government bears the capital expenditure.[301]

3.3.3.4 Hybrid Annuity Mode (HAM)

The Hybrid Annuity Model (HAM) is another innovative public-private partnership financing mechanism. Under HAM, the government pays 40% of the project cost to the private developer during the construction phase in milestone-linked tranches, ensuring liquidity and reducing the financial burden on the developer. The remaining 60% is arranged by the developer through a mix of equity and debt and is paid back by the government as deferred annuity payments over the concession period, typically 15–20 years, along with interest and O&M payments. These annuity and O&M payments are linked to the performance of the facility, incentivizing efficient and sustained operation. HAM balances risk between the public and private sectors, encourages private investment, and ensures long-term accountability and quality in service delivery. While it has been widely used in sectors like highways and sewage treatment, its application is expanding to solid waste management to attract private investment and improve operational outcomes.[302]

3.4 Policy and Regulatory Enforcement: Challenges and Interventions

India faces a complex set of policy challenges in its endeavor to manage rapidly increasing volumes of solid waste, largely driven by urbanization and changing consumption patterns. With the Solid Waste Management Rules, 2026 notified in January 2026 and in force from 1 April 2026, alongside the continuing Swachh Bharat Mission–Urban (SBM-U) 2.0 and the newly launched Dumpsite Remediation Accelerator Programme (DRAP), India's SWM framework has moved decisively from prescriptive intent toward measurable, time-bound accountability. Despite this regulatory upgrade, effective implementation, particularly concerning landfill management, remains a significant hurdle. The nation's approach to SWM is broadly categorized into regulatory and enabling policies, each presenting distinct challenges and requiring targeted interventions.[303]

3.4.1 Policy Challenges

A primary challenge lies in the weak enforcement of segregation and processing mandates. Even with explicit directives such as the SWM Rules, 2026 and SBM-U 2.0, which now mandate 100% source segregation into four streams (wet, dry, sanitary, and special-care waste), scientific processing, and minimization of landfill dependence, consistent implementation is often lacking across Indian cities, as policies are still not holistically addressing the issue of sustainable landfill management. Understanding the issue more comprehensively, we can map out the following few challenges where policy implementation is plagued and needs utmost attention.[304]

1. **Legacy Landfills: From a Prescriptive Mission to a Structured National Programme**

   Challenge: India has made significant strides in addressing legacy landfills. SBM-U 2.0's "Lakshya Zero Dumpsites" initiative set a target of achieving "Garbage-Free Cities" by September 2026, and this target is now backed by a dedicated implementation vehicle: the Dumpsite Remediation Accelerator Programme (DRAP), formally launched in November 2025. DRAP prioritizes the 214 highest-impact dumpsites across 202 ULBs, which together hold roughly 80% of India's remaining legacy waste (about 8.8 crore metric tonnes), and commits to 100% clearance of these sites within one year of adoption, backed by Central Financial Assistance of ₹550 per tonne and a multi-tiered digital monitoring system.[305,306] The SWM Rules, 2026 reinforce this further by introducing, for the first time, an explicit regulatory provision for time-bound legacy dumpsite remediation, moving the mandate beyond a mission target toward a rule-backed obligation. However, the framework still stops short of a single, legally enforceable national deadline covering all dumpsites: DRAP's structured financing and oversight remain concentrated on the 214 priority sites, leaving smaller and medium dumpsites outside its ambit without an equivalent time-bound, funded pathway. The ultimate responsibility for on-ground implementation also continues to rest with resource-constrained ULBs, even as MoHUA and CPCB provide technical guidance and funding.

   Intervention: DRAP's leadership-driven adoption model, ring-fenced financing, and public dashboards should be extended, through cluster-based tendering, to the smaller and medium dumpsites currently outside its priority list, so that mobilisation costs are spread across bundled contracts rather than left commercially unviable on a standalone basis. The time-bound remediation obligation now embedded in the SWM Rules, 2026 should be operationalised through binding subordinate guidelines and penalty provisions for non-compliance, rather than relying on DRAP's mission-mode targets alone, to ensure legal enforceability and accountability across all States and Union Territories.

2. **Inadequate Monitoring of Methane and Leachate Emissions**

   Challenge: The SWM Rules, 2026 continue to cap methane gas concentrations at landfills at 25% of the lower explosive limit, and now go further by introducing a dedicated landfill gas (LFG) capture mandate at sanitary landfills. Yet Indian cities are still struggling to comply: limited public knowledge of waste segregation and open, unmonitored garbage dumps continue to impede segregation at source, and most landfills still lack the infrastructure to monitor and capture methane or treat leachate. A further design tension has emerged with the new rules: as four-stream source segregation is enforced more strictly, the organic content reaching landfills is expected to decline over time, raising questions about how LFG capture infrastructure should be sized, sequenced, and financed so it is not built for a waste stream that is meant to shrink.

Intervention: Mandate and fund the installation of methane capture systems and leachate treatment infrastructure in all existing and new landfills, with real-time monitoring integrated into the SWM Rules, 2026's centralised digital portal, and strict penalties for non-adherence. LFG infrastructure decisions should be made site-specific rather than uniform, distinguishing legacy dumpsites, active mixed-waste sites, and future residual landfills, and should favour modular, scalable gas systems over fixed large-scale installations so capacity can be adjusted as segregation reduces organic loads. The Supreme Court's directions under Civil Appeal No. 6174/2023, requiring District Special Cells to undertake fortnightly progress reporting and virtual spot inspections, should be leveraged to enforce these monitoring obligations.

3. Infrequent Penalties for Waste Non-Segregation

Challenge: Under the SWM Rules, 2016, ULBs[307] held the authority to levy "spot fines" for non-segregation, but the amount was left to municipal discretion, producing inconsistent and often ineffective enforcement. The SWM Rules, 2026 mark a shift by introducing environmental compensation on a polluter-pays basis as a nationally applicable principle, rather than leaving penalty structures entirely to local discretion. However, the Rules do not yet prescribe a detailed, tiered national penalty schedule distinguishing households from commercial and bulk generators, and state-level audit reports continue to highlight weak enforcement and inconsistent penalty realisation as a persistent barrier to segregation compliance[308].

Intervention: MoHUA and CPCB should operationalise the SWM Rules, 2026's environmental compensation provision into a clear, tiered penalty structure, distinguishing households (moderate first-time fines with escalating penalties for repeat offences) from commercial establishments and bulk generators (higher penalties linked to waste generation volume). State-level precedents such as the Maharashtra Non-biodegradable and Garbage (Control) Act, 2006, which provides for imprisonment and substantial fines, could inform this national template. The District Special Cells constituted under the Supreme Court's May 2026 order should be tasked with tracking and reporting the actual realisation of environmental compensation, not merely its notification, to ensure penalties translate into behavioural change on the ground.[309]

4. Lack of "No Future Dumpsite" Planning

Challenge: Earlier CAG audits found that most States lacked reliable data on projected future waste generation and could not confirm the adequacy of their waste-handling capacity, reflecting a planning system still oriented toward a linear "take-make-dispose" model rather than a circular economy. The SWM Rules, 2026 respond to this in part by confining landfilling strictly to non-recyclable, non-recoverable, and inert waste, introducing an Extended Bulk Waste Generator Responsibility (EBWGR) framework, and mandating a phased rise in Refuse-Derived Fuel (RDF) substitution for cement and waste-to-energy industries, from 6% at implementation to 15% within six years. These provisions push the system toward reduction and recovery rather than continued landfill dependence, but their success still depends on States systematically collecting and using future waste-generation data, which remains inconsistently available.

Intervention: The centralised digital portal established under the SWM Rules, 2026 should be used to mandate systematic, standardised state-wise data collection on projected future waste generation, so that this data directly informs circular-economy planning rather than being collected as a compliance formality. This should feed into state-wise strategies for eliminating dependence on new landfills, backed by mandated investment in MRFs, composting plants, and recycling infrastructure, with the EBWGR framework and phased RDF substitution mandate under the SWM Rules, 2026 rigorously enforced as the primary levers of this transition.

Other Enabling Interventions: Fostering Awareness and Sustainable Practices: These interventions aim to educate, incentivize, and facilitate positive behavioral change.

1. **Comprehensive Public Awareness and Education Campaigns:**

Intervention: Launch sustained, culturally sensitive Information, Education, and Communication (IEC) campaigns across both urban and rural areas, leveraging Swachh Bharat Mission's reach, that explain the four-stream segregation mandate introduced under the SWM Rules, 2026, and not merely the earlier wet-dry distinction. These campaigns must clearly explain the 'why' (environmental and health impacts of poor waste management) and 'how' (practical steps for segregation and responsible disposal). Integrate waste management into school curriculam to cultivate responsible habits from a young age..

2. **Incentives for Segregation and Decentralized Processing:**

Intervention: Implement user fee structures that incentivize segregation, potentially offering reduced fees for households or establishments that consistently segregate their waste. Provide subsidies, technical assistance, or recognition for households, communities, and businesses undertaking on-site composting or setting up decentralized recycling units. Promote "Waste-to-Wealth" initiatives that convert segregated waste streams into valuable resources, creating economic incentives.

3. **Capacity Building and Technological Adoption:**

Intervention: Provide regular and comprehensive training for both formal and informal waste workers on handling segregated waste, safety protocols, and the use of modern equipment. Allocate significant financial resources for the development of robust waste collection infrastructure, material recovery facilities (MRFs), composting plants, and scientifically engineered landfills (for residual waste). Build on the monitoring architecture already piloted under DRAP, such as GPS/RFID-enabled vehicle tracking and public dashboards, to scale smart waste management solutions such as sensor-fitted bins and data analytics for optimized routing and efficient management.

4. **Formalizing the Informal Sector:**

Intervention: Actively integrate informal waste pickers and recyclers into the formal, regulated waste management system. The registration of informal waste workers now mandated under the SWM Rules, 2026 should be anchored to the existing National Action for Mechanised Sanitation Ecosystem (NAMASTE) enumeration and e-KYC database, rather than creating a duplicate registration process, with registration linked to identity cards, access to protective gear, training, and direct linkages to Material Recovery Facilities. This formalization improves segregation and recycling rates while enhancing workers' livelihoods and working conditions.

By systematically operationalising these regulatory measures under the SWM Rules, 2026, and by extending DRAP's structured, time-bound remediation model to dumpsites beyond its current priority list, India can move closer to achieving sustainable landfill management and a more circular approach to its solid waste, thereby significantly contributing to its climate commitments.

Table 29: Analysis of key policy initiatives in waste management in India and their implementation gaps

Key Policy Initiatives	Type	Waste Hierarchy Level	Core Provisions	Implementation Gaps	Sources
Solid Waste Management Rules, 2016	Regulatory	Recycling, Recovery, Disposal	Mandates source segregation (wet/dry/hazardous), door-to-door collection, user fees, bulk generator responsibility, composting, waste-to-energy, and integration of informal sector.	Poor enforcement of segregation (less than 20% ULBs effective as of 2022), only 50% of waste scientifically processed by 2021, insufficient composting/recycling infrastructure, funding and technical gaps at ULB level.	CPCB Annual Report 2021-22, p.4, p. 29 CAG Audit Report 2022, p. 42 CAG Audit Report 2022, Ch. II & III
Plastic Waste Management Rules (2016; Amended 2018, 2021, 2022)	Regulatory	Prevention, Recycling, Recovery	EPR for producers, SUP ban, thickness restrictions, mandatory CPCB registration, plastic credit trading, environmental compensation for non-compliance.	Low formal recycling rate (16-25%), weak enforcement of SUP bans, EPR compliance gaps, informal sector dominance, lack of affordable alternatives, monitoring/accountability issues.	CPCB PWM AR 2020-21 India Plastics Pact AR 2023-24, p. 18-20 CEEW, 2022, p. 1
E-Waste (Management) Rules (2016 & 2022)	Regulatory	Reuse, Recycling, Recovery	EPR for e-waste, collection targets, online registration, expanded product coverage, EPR certificate trading, incentives for refurbishment, stricter penalties.	Only ~33% of e-waste formally collected (2021-22), informal sector still dominant, low consumer awareness, insufficient collection points, infrastructure gaps.	PIB, 2023 CEEW, 2022, p. 1
Bio-Medical Waste Management Rules, 2016	Regulatory	Disposal (Treatment)	Segregation at source, color-coded containers, phase-out of chlorinated plastics, barcoding/GPS, emission standards, mandated CBWTFs, worker training.	Small clinics/labs often remains non-compliant, poor segregation, rural areas underserved, expansion of healthcare during the COVID-19 pandemic also saw huge increases in biomedical waste- straining the capacity of treatment facilities and revealing the need for more investment in waste infrastructure and training under these rules.	Dhloe et al.,2024 CPCB, BWM Report 2023, pp. 5, 18, 21 CPCB, BWM Report 2022, p. 5
Construction and Demolition Waste Management Rules, 2016	Regulatory	Reuse, Recycling	Segregation, designated collection centers, C&D management plans, recycling targets, polluter pays principle, use of recycled materials in public projects.	Only ~1% of C&D waste recycled (2020), few recycling plants (13 of 53 cities by 2020), illegal dumping persists, poor awareness/enforcement among builders.	CSE, 2020 Down to Earth, 2020

Key Policy Initiatives	Type	Waste Hierarchy Level	Core Provisions	Implementation Gaps	Sources
Hazardous and Other Wastes (Management & Transboundary Movement) Rules, 2016	Regulatory	Prevention, Minimization, Reuse, Recycling, Recovery, Disposal	Covers industrial/ hazardous waste, EPR for tyres, Basel Convention compliance, manifest system, strict protocols for handling, packaging, transport, and disposal.	There are 46 operational TSDFs (Treatment, Storage and Disposal Facilities) in the country. However, some states/UTs still lack TSDFs, and several regions report a gap between hazardous waste generated and disposal capacity. Prevalence of illegal dumping & on-site storage, poor treatment/ monitoring, and uneven implementation	CPCB National Inventory 2023-24, pp. 14–18 (PDF) CAG Report ,Chapter 7
SBM (Urban & Rural), 2014-Present	Enabling	Prevention, Reuse, Recycling	Funding for infrastructure, IEC campaigns, capacity building, Swachh Survekshan rankings, ODF and ODF+ targets, support for composting, MRFs, and waste-to-energy.	Unavailability of rural data on waste management, Inadequate levy of penalties for violations, workforce shortages. While behavior change campaigns under SBM have led to improvements in waste segregation and cleanliness, sustaining these changes remains a challenge, especially in rural and peri-urban areas	CAG Audit Report, 2022
Atal Mission for Rejuvenation and Urban Transformation (AMRUT), 2015	Enabling (Centrally sponsored scheme for infrastructure)	(Primarily targets liquid waste and infrastructure; not directly aligned with solid waste hierarchy)	Urban infrastructure mission (water supply, sewage, stormwater drainage, urban transport, green spaces). No dedicated solid waste component, but investments in sanitation and drainage indirectly support waste management (e.g., modern STPs reduce dumping in drains, green spaces can host composting centers).	Exclusion of solid waste component in the initial AMRUT guidelines. Cities had to rely on SBM or their own funds for waste infrastructure. Siloed sectoral approach led to less holistic outcomes. By 2020, many projects delayed or incomplete due to capacity constraints, indirectly slowing environmental benefits affecting waste, highlighting a need for integrated solid waste management.	AMRUT Guideline, 2015 MOHUA. 2021 Niti Aayog, 2021

Key Policy Initiatives	Type	Waste Hierarchy Level	Core Provisions	Implementation Gaps	Sources
National Action Plan for Municipal Solid Waste Management, 2015	Enabling (Policy plan with targets and guidelines; not legally binding)	All levels – prevention of littering/open dumping, reuse/recycle, recovery (energy/ compost), disposal (engineered landfills)	Strategic framework (MoEFCC/CPCB) with targets: 100% door-to-door collection, 100% segregation at source, 100% processing/disposal by 2019. Emphasizes processing facilities, sanitary landfills, elimination of open dumping/burning, legacy dumpsite remediation, and clear stakeholder roles.	Targets unmet: By 2021, only ~50% of MSW was processed, enforcement depended on local/state commitment. Gaps in funding, technical support, and coordination while objectives overlapped with SBM, causing confusion. Lack of clear accountability and non-mandatory targets led to uneven implementation.	CPCB Annual Report 2020-21, p. 4 PM India Press Release, 2021 CAG Audit Report, 2022
Solid Waste Management Rules, 2026	Regulatory	Prevention, Reuse, Recycling, Recovery, Disposal	Expands coverage to rural/urban, mandates 4-way segregation, digital compliance portal, Extended Bulk Waste Generator Responsibility, real-time monitoring, integration of informal sector, focuses on circular economy	Significant implementation readiness gaps remain, including inadequate segregation and collection infrastructure, limited processing capacity, absence of standardised processor authorisation procedures, fragmented SPCB–ULB approval systems, limited institutional and technical capacity, financing constraints, and challenges in enforcing compliance across ULBs.	Ministry of Environment, Forest and Climate Change. (2026, January 27). Solid Waste Management Rules, 2026
Dumpsite Remediation Accelerator Programme (DRAP)	Programme / Mission	Legacy Waste Remediation, Land Reclamation, Methane Mitigation	Mission-mode programme targeting 214 high-impact legacy dumpsites across 202 Urban Local Bodies (ULBs), accounting for approximately 80% of India's remaining legacy waste. The programme aims to accelerate scientific remediation of legacy dumpsites, prevent the creation of new dumpsites, reclaim land for productive use, provide technical and financial support to ULBs, and strengthen monitoring and implementation through digital systems.	Limited prioritisation of small and medium-sized dumpsites, as the programme primarily focuses on high-impact legacy dumpsites. This leaves many smaller sites outside the scope of dedicated technical and financial support, potentially delaying comprehensive remediation and increasing the risk of continued environmental impacts.	DRAP 2025

3.5 The Judiciary as a Key Player

3.5.1 India's Judiciary: A Pioneer in Waste Management

India's judiciary has become an unparalleled force in waste management and environmental protection. Driven by expanding statutory interventions and a commitment to broad environmental safeguarding, the **Supreme Court of India's activism in shaping environmental jurisprudence since the 1980s is unmatched globally.** Unlike any other judiciary, it has dedicated immense time, effort, and creativity to mitigating the adverse effects of solid waste on the environment over the past two decades.[310]

Through landmark interventions spanning two decades, India's judicial system, led by the **Supreme Court and the National Green Tribunal (NGT),** with support from State High Courts, has profoundly transformed the nation's solid waste management crisis. These judicial bodies have become crucial in enforcing environmental compliance and establishing precedents that have fundamentally reshaped municipal waste management practices nationwide. Their involvement evolved from addressing localized pollution to implementing comprehensive national frameworks, showcasing the judiciary's growing influence in environmental governance. Consistently, courts have interpreted the **fundamental right to life under Article 21 of the Constitution to encompass the right to a healthy environment,** compelling government authorities to take concrete action on waste management.[311]

3.5.1.1 The Almitra H. Patel Case: A Foundational Ruling

The Indian judiciary frequently intervenes in response to Public Interest Litigations (PILs) concerning inadequate waste management, environmental pollution, and public health. A seminal example is **Almitra H. Patel vs. Union of India,** widely regarded as a pivotal case that laid the groundwork for modern solid waste management regulations in the country.[312]

Almitra H. Patel vs. Union of India (2000)[23]

Filed in 1996 as a PIL under Article 32, this case by environmental activist Almitra H. Patel exposed Delhi's severe waste management failures and violation of the right to a clean environment under Article 21 of the Constitution. Municipal Corporation of Delhi (MCD) was accused of neglecting its statutory duties under the Delhi Municipal Corporation Act, 1957, leading to unchecked pollution of air, water, and the Yamuna River — posing serious health risks to the citizens.

The petitioner highlighted the municipality's disregard for existing environmental laws and stressed the urgent need for effective waste management amid rapid urbanization. The Supreme Court, recognizing the gravity of the issue, issued a landmark judgment in 2000 mandating the creation of an eight-member expert committee — including Patel — to review and recommend reforms for solid waste management in Class I cities.

The committee's mandate included examining waste collection, segregation, recycling, and financing, along with a review of the municipal by-laws. Its findings influenced the Municipal Solid Waste (Management and Handling) Rules, 2000, which emphasized source segregation and scientific disposal. While the judgment initiated systemic reform, challenges in implementation — such as funding and infrastructure — led to ongoing Supreme Court oversight in the years that followed. This landmark judgment by the Supreme Court of India, delivered in multiple orders between 1996 and 2000, with subsequent proceedings transferred to the National Green Tribunal (NGT), highlighted the judiciary's role in enforcing environmental accountability and catalyzed systemic reforms in waste management practices across India

3.5.1.2 Transition to Specialized Environmental Jurisdiction

A significant institutional shift occurred in 2014 when the Supreme Court, acknowledging the need for specialized environmental expertise, transferred solid waste management matters to the NGT.[313] In its order dated September 2, 2014, in *Almitra H. Patel vs. Union of India & Others* (Writ Petition No. 888/1996), the Supreme Court observed that "handling of solid municipal waste is a perennial challenge and would require constant taking note of dereliction, if any, issuing suitable directions consistent with the said Rules and direction incidental to the purpose underlying the Rules." Recognizing the ongoing nature and need for consistent oversight in such matters, the Court deemed the NGT, established under the National Green Tribunal Act, 2010, as the most suitable body to handle these issues.

This transfer marked a crucial pivot from general constitutional jurisdiction to specialized environmental adjudication. It was justified by the Supreme Court's recognition of the NGT's mandate and expertise in environmental matters, allowing for more technical and focused attention on waste management challenges.

3.5.1.3 Timeline of Judicial Rulings

Figure below illustrates key judicial rulings in waste management, from early environmental cases in the 1980s to recent orders in 2024. This timeline showcases an evolving judicial approach: from reactive problem-solving (1980s-2000s) to systemic framework-building (post-2010) and, more recently, proactive monitoring (post-2020).

START

1986

L.K. Koolwal v State of Rajasthan (Rajasthan High Court) – Recognized sanitation as part of the fundamental right to life under Article 21, mandating municipal authorities to address waste management.

2002

Municipal Corporation of G Mumbai vs. K.V. Shramik S (Supreme Court) – Addres issues in waste manageme operational reforms across

2010

Establishment of NGT – as per National Green Tribunal Act.

2014

Institutional Shift to NGT – Supreme Court transferred solid waste management cases (including Almitra Patel) to NGT, citing its technical expertise under the NGT Act.

2016

Ban on open waste burning (NGT) – Banned open waste burning and mandated strict implementation of Solid Waste Management Rules, 2016.

2022

NGT Waste Management Orders – compliance on sewage treatment a disposal imposed on Andhra Prade Pradesh, Jammu and Kashmir, Kar Madhya Pradesh, Maharashtra, Ma Nagaland, New Delhi, Puducherry, F Sikkim, Tamil Nadu, Telangana, and

20

NGT W sewag Chand Diu, N Ladak

1996

B.L. Wadhera v Union of India (Supreme Court) – Compelled Municipal Corporation of Delhi to fulfil their statutory waste management duties in collection, removal and disposal of garbage and other waste from the city.

1999

A.P. Pollution Control Board vs. M.V. Nayudu (Supreme Court) – Reinforced the need for expert-driven environmental tribunals, influencing NGT's establishment in the future.

2000

Almitra H. Patel v Union of India (Supreme Court) – Landmark judgment, ordering scientific waste disposal, landfill site identification, and compost plant establishment. Declared poor waste management a constitutional rights violation. Paved the way for Solid Waste Management Rules 2000.

Greater
Sangh and Ors
sed labour
ent, impacting
s the nation.

23

Waste Management Orders – Fines for non-compliance on
ge treatment and garbage disposal imposed on Assam, Bihar,
digarh, Chhattisgarh, Dadra and Nagar Haveli and Daman and
lew Delhi, Goa, Gujarat, Haryana, Himachal Pradesh, Jharkhand,
kh, Odisha, Tripura, Uttar Pradesh, and Uttarakhand.

Fines for non-
and garbage
esh, Arunachal
nataka, Kerala,
nipur, Meghalaya,
Punjab, Rajasthan,
d West Bengal.

2024

NGT Waste Management Orders – Fines for non-compliance on sewage treatment and garbage disposal imposed on Punjab and Uttar Pradesh.

2026

Bhopal Municipal Corporation v. Dr Subhash C. Pandey (Supreme Court) – Issued nationwide directions for the SWM Rules, 2026. Declared non-compliance penal rather than administrative, delegated Environment (Protection) Act powers to District Collectors, and constituted a Supreme Court empowered Monitoring Committee of Union Secretaries.

3.5.2 Challenges from Judicial Mandates

While well-intentioned, certain judicial interventions have inadvertently created challenges for sustainable waste management. Directives focused solely on landfill elimination have, at times, **shifted attention away from crucial upstream actions like source segregation and recycling,** which are foundational to the waste hierarchy (Reduce, Reuse, Recycle, Recover). This narrow focus has led municipalities (ULBs) to prioritize quick compliance, often resorting to **waste-to-energy (WtE) or incineration technologies** as expedient solutions, despite them being lower on the waste hierarchy and often environmentally and economically unsustainable.

This overemphasis on end-of-pipe solutions has **diverted investment from decentralized recycling systems and segregation-at-source initiatives.** Furthermore, these alternative treatment methods, like incineration, have raised new concerns, including **adverse health impacts,** with reports revealing some Delhi WtE plants exceeding legal dioxin emission limits. Additionally, the livelihoods of **informal waste pickers, vital to India's recycling sector, have been jeopardized** as recyclable materials are increasingly funneled into incinerators instead of recycling chains.

Case Studies Highlighting Challenges:

01

The Mavallipura Landfill Crisis (2012): The closure of this heavily polluting landfill near Bangalore, though judicially mandated, triggered a city-wide garbage crisis and continued pollution, demonstrating the complexities of reactive closures without systemic alternatives.[314]

02

Supreme Court Clears WtE Plant in Narela-Bawana (Jan 2025): The Supreme Court's approval of this WtE plant, despite its capacity to process significant waste, faces strong public opposition due to persistent pollution and health concerns, highlighting the tension between infrastructure development and environmental justice.[315]

Recent Judicial Interventions:

Strengthening Compliance

The Supreme Court recently intervened to tighten oversight in the National Capital Region (NCR). On 26th April, 2025, in response to an M.C. Mehta petition, the Court directed Delhi, Uttar Pradesh, Haryana, and Rajasthan to appoint senior nodal officers to ensure **100% segregation and timely collection of solid waste.**[316] The bench also recommended the Centre consider reducing the 18% GST on products made from recycled construction and dust waste. This reflects a more comprehensive and forward-looking strategy, as the Court also ordered states to submit **realistic 25-year MSW generation projections and corresponding action plans.**

While the Indian judiciary has been instrumental in driving waste management reforms, establishing legal precedents, and enforcing environmental accountability, some decisions have led to unintended consequences. These often stem from inadequate municipal planning, weak enforcement, and a reactive rather than holistic approach. For judicial activism to fully support sustainable waste management, courts must emphasize source segregation, robust recycling infrastructure, community welfare, and strong enforcement, ensuring environmental justice aligns with long-term sustainability goals.

3.6 The Role of Behavior

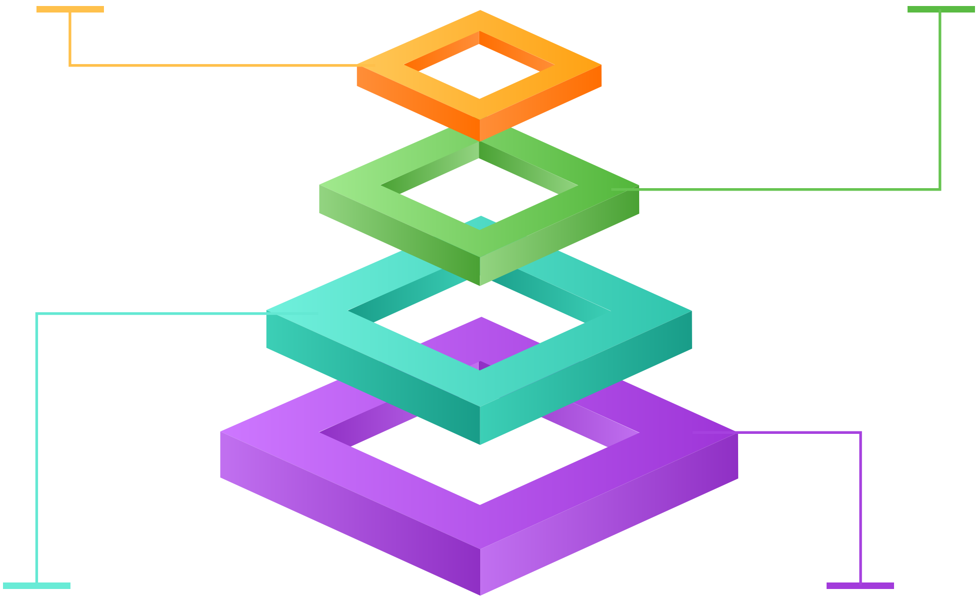
Effective SWM in India, crucial for mitigating methane emissions and reducing landfill dependency, hinges significantly on robust behavior change communication (BCC). Amidst rapid urbanization and escalating waste generation, infrastructure and policy reforms alone are insufficient; active citizen engagement and community participation are essential to foster sustainable waste practices. Implementing targeted BCC strategies that address local needs and cultural sensitivities is paramount for successful waste management.

3.6.1 Behavioral Barriers in SWM

Several ingrained behavioral barriers and social norms impede scientific waste management practices, directly contributing to unscientific dumping and consequent methane generation:

Lack of Awareness and Knowledge: A widespread lack of awareness regarding the environmental and health impacts of improper waste disposal directly leads to poor segregation and disposal practices. For instance, a 2024 survey in Bhopal found only **52% of households were familiar with general SWM concepts,** highlighting significant knowledge gaps in recyclability and correct segregation. This cognitive barrier increases the effort required for proper disposal, discouraging consistent behaviour change and ensuring mixed waste reaches dumpsites, fueling methane production.[317]

Apathy and Low Risk Perception: A prevailing "someone else's responsibility" mentality leads to careless disposal in public spaces. When citizens perceive the risks of poor waste management (e.g., health hazards, environmental degradation) as low or distant, motivation for responsible behaviour wanes. This apathy directly results in increased littering and unsegregated waste entering the municipal stream, overloading collection systems, and ultimately contributing to landfill volumes.[318]



Infrastructure Barriers: Even willing participants face hurdles if municipal waste collection systems are inconsistent. Irregular or unavailable door-to-door collection of segregated waste forces households to revert to mixing waste or dumping. The Bhopal study noted that while **50% of respondents segregated waste regularly,** others cited lack of time, space for multiple bins, or absence of separate collection as barriers, underscoring systemic inefficiencies that undermine citizen efforts and push more mixed waste to landfills.

Social Hierarchies and Gender Roles: Socio-cultural norms, particularly caste and gender dynamics, influence participation and recognition in waste management. Women, especially from marginalized communities, often undertake informal waste picking and segregation but face discrimination. These hierarchies restrict their empowerment and reduce the effectiveness of community-based initiatives vital for source segregation and decentralized waste processing, which are critical for landfill diversion.[319]

3.6.2 Strategies to Drive Behaviour Change in Waste Management

Driving profound behaviour change in SWM requires a multi-pronged approach, fostering synergy between government, private entities, and community actors. The **SBM** has been transformative in raising awareness, although sustained, long-term behavioural shifts still require concerted effort.

These campaigns are foundational for raising awareness about segregation, recycling, and composting. Success stories like Indore, which leveraged self-help groups, religious leaders, and schools in mass awareness drives, demonstrate how IEC can transform habits, leading to widespread adoption of source segregation and home composting. Effective campaigns embed sustainable practices early, building a culture of environmental responsibility that directly reduces the quantity and organic content of waste reaching landfills.

- **Financial Rewards:** Discounts on waste collection fees or property tax benefits for segregating households prove effective. The **Brihanmumbai Municipal Corporation (BMC)** offers a **15% rebate on property tax** for housing societies segregating and processing wet waste on-site, a model also adopted by the **Municipal Corporation of Delhi.**[320]
- **Market-Driven Incentives:** India's extensive *kabadiwala* (informal waste buyer) network offers a robust, market-driven incentive for source segregation. Citizens sell segregated dry waste (e.g., newspapers at ₹10/kg, e-waste at ₹50/kg), directly supporting material recovery and diverting vast quantities from landfills.[321]
- **Technological Incentives:** Schemes like Hong Kong's Reverse Vending Machine (RVM) pilot offered instant rebates (HKD 0.1 per plastic beverage container), facilitating convenient recycling and directly reducing plastic waste destined for landfills.[322]

A mix of rewards and penalties ensures compliance with waste management rules. Fines for non-compliance, such as **Rs 5,000 to Rs 20,000 per tonne of plastic waste** for improper handling under Plastic Waste Management Rules, 2016, and fines up to **Rs 1 lakh for EPR non-compliance,** send a clear message that improper disposal is legally punishable. Municipal by-laws also impose penalties for wrongful garbage disposal or burning, reinforcing desired behaviours and preventing illegal dumping that exacerbates landfill issues.[324]

Bottom-up community involvement is critical for lasting change. Mobilizing Resident Welfare Associations (RWAs), youth, and NGOs to act as "waste management champions" can galvanize peers, lead local drives, and organize clean-up events. Empowering communities to manage decentralized composting and recycling initiatives directly reduces landfill dependency and promotes local solutions, fostering a sense of ownership.

Case Studies: Driving Behaviour Change on the Ground

These initiatives demonstrate the tangible impact of behaviour change on waste diversion and sustainable management:

- **Rehmat Nagar Rag Picker's Colony –** CURE India: In Rourkela, Odisha, CURE India transformed Rehmat Nagar, a settlement reliant on rag picking, by integrating its residents' existing waste segregation skills into the city's formal SWM system. By promoting awareness, advocating for formalization under the National Urban Livelihood Mission (NULM), and leveraging the community's ingenuity, CURE fostered a shift from informal waste disposal to more formal, sustainable practices. This initiative not only improved livelihoods but also formalized waste diversion from landfills.[325]
- **Su-Dhara by Vertiver – Waste-to-Wealth:** Launched under the Government of India's Waste-to-Wealth initiative in East Delhi, Su-Dhara exemplifies behaviour change by transforming temple flower waste into compost. By installing a **300 KG rotating-drum composting unit** at Durga Mandir and engaging community champions, the project capitalized on the emotional connection to sacred offerings. Despite the COVID-19 lockdown, the temple community sustained composting, producing fresh batches by July 2020. This initiative shifted attitudes from passive disposal to active segregation and composting, showcasing how aligning emotional values with practical, visible outcomes fosters sustainable waste management and reduces organic waste reaching landfills.[326]
- **SORT (Segregation of Organic garbage for Recycling and Treatment) - by IPCA:** The IPCA's SORT initiative decentralizes organic waste management through source segregation, aerobic composters, and plastic waste channelization for recycling. Since 2018, SORT has expanded across Delhi NCR and other Indian cities, preventing over **1,049 metric tons of waste from reaching landfills** and generating over **150,000 kg of organic compost** by July 2024. Operating in **350+ societies across Delhi, Mumbai, Pune, and Bangalore,** SORT's success is attributed to extensive training, awareness campaigns, and community incentives, empowering societies to achieve near zero-waste status, cutting landfill dependency, and reducing GHG emissions from waste transport and landfill processes.[327]


सूखा Dry
गीला Wet

CHAPTER 4:

WAY FORWARD

ROADMAP TO SUSTAINABLE WASTE MANAGEMENT

From the above chapters, it is evident that India's rapid urbanization and associated waste generation necessitate urgent and comprehensive urban sustainability actions. This is not only to ensure a cleaner environment domestically, but to meet critical global climate targets. The task at hand presents a challenging picture.

4.1 Opportunities, Co-Benefits, and Economic Potential

The picture painted in the previous chapters has prompted a significant regulatory response, in the SWM Rules 2026. This comprehensive overhaul of waste governance captures all ends of the value chain, introducing necessary updates in the system. Notably, the Supreme Court of India, in orders dated 29 April and 5 May 2026, has also directed District Collectors to constitute Special Cells for implementation oversight — marking a decisive shift from aspirational policy to immediately enforceable obligation.

While figures showcased in previous chapters paint a grim picture in terms of landfill emissions and climate change, they also represent strong opportunities. Some of the direct areas of opportunity include (but are not limited to):

- **Methane Capture and WtE Potential:** Capturing LFG can reduce methane emissions by **60-90%**. Nationally, India's solid waste disposal sites (SWDS) could generate **5,167 MW** to **14,355 MW** of power,[328] supporting both GHG mitigation and renewable energy targets. Current Waste-to-Energy plant capacity stands at **17,600 TPD.**[329] However, the SWM Rules 2026 also introduce a phased RDF substitution mandate, rising from 6% at implementation to 15% within six years for cement and WtE industries, which will require significant upgrades to segregation and processing infrastructure to be viable.
- **Biomining and Biocapping:** These processes are crucial for remediating legacy waste. Rajkot's Nakrawadi dumpsite (16 lakh tonnes) was transformed into a 20-acre urban forest through biomining, segregating RDF for WtE, semi-compost for land enrichment, and inert material for secured landfills.[330] The SWM Rules, 2026, prioritize biomining over capping for legacy waste management.[331]
- **Circular Economy and Resource Recovery:** The total circular economy potential for waste in India potentially exceeds **$15 billion annually. The SWM Rules 2026 emphasize on the waste hierarchy — prevention → reduction → reuse → recycling → recovery → disposal — in law, formally shifting the system's legal basis from disposal-led management toward circular economy outcomes.**[332]

Besides the above, it's important to understand the range of co-benefits that result from better management of landfills. The co-benefits, as noted in Chapter 2, include air quality and public health improvement, biodiversity gains, and socioeconomic benefits.

Interventions under **SBM-U 2.0,** which has allocated over ₹776 crores specifically for bioremediation and land reclamation, significantly reducing harmful emissions and enhancing living conditions for affected communities. Furthermore, the integration of waste-pickers into formal waste management systems, exemplified by Pune's SWaCH cooperative, serves as a crucial public health intervention by reducing their exposure to hazardous waste and improving occupational safety.

Further, for a country which seeks to augment its economy in an accelerated manner, large-scale models of effective landfill management promise strong rewards.

Sustainable landfill management offers substantial economic benefits at both municipal and national levels in India. The remediation of legacy dumpsites is a strategic economic move that reduces long-term environmental liabilities while simultaneously reclaiming valuable urban land. This reclaimed land can then be repurposed for public use, industrial development, or transformed into much-needed green spaces. A significant example is the **DRAP's ambitious goal to reclaim 214 large dumpsites across priority ULBs will free acres of land by remediating 8.8 crore MT of legacy waste.**[333,334]

Beyond land reclamation, LFG-to-energy projects, such as bio-CNG plants in Indore and Pune, demonstrate strong economic viability. These initiatives generate revenue through the sale of renewable energy and compost, simultaneously reducing the costs associated with traditional waste disposal and pollution control. The 2700 lakh tonne legacy waste in India underscores both the liability and the economic reclamation opportunity.[335]

Despite these promising opportunities, the economic viability of some waste-to-energy plants can be constrained by factors such as the low calorific value and high moisture content, alongside financial and administrative challenges faced by ULBs. Nevertheless, social cost-benefit analyses consistently indicate that investments in decentralized composting, biomethanation, and recycling yield higher returns than conventional landfilling or incineration, especially when accounting for the full spectrum of environmental and health benefits.

4.2 India's Existing Policy and Regulatory Landscape

India does not have a single, overarching national policy with specific targets for reducing methane emissions from the waste sector. Instead, the approach is multifaceted, relying on a combination of existing policies, missions, along with global commitments noted in previous chapters. Against such a backdrop, it's useful to situate India's policy ecosystem within context.

- *SBM and Swachh Bharat Mission-Urban (SBM-U 2.0):* This is the primary driver of change. While its main goal is to create "Garbage Free Cities," its focus on *scientific solid waste management* directly addresses methane emissions. The mission's key objectives that serve as implicit methane targets are:

  Source segregation: The mandatory segregation of waste into dry, wet, and hazardous categories is a cornerstone.

  Waste processing: The goal is to ensure 100% of urban waste is scientifically processed, minimizing the amount sent to dumpsites.

- **Solid Waste Management Rules, 2026 –** The SWM Rules 2016 were superseded by the SWM Rules 2026[336] (notified 28 January 2026, effective 1 April 2026), representing the most comprehensive overhaul of India's waste governance since 2016. Key additions include: mandatory four-stream segregation (wet, dry, sanitary, special care); an Extended Bulk Waste Generator Responsibility (EBWGR) framework covering generators with floor area ≥20,000 sq.m. or waste output ≥100 kg/day; a centralised digital monitoring portal with environmental compensation for false reporting; a phased RDF substitution mandate for cement and WtE industries; and quarterly progress reporting on legacy dumpsite remediation. The Supreme Court of India, in orders of 29 April and 5 May 2026 (C.A. No. 6174/2023), has directed District Collectors to constitute Special Cells for oversight and submit fortnightly compliance reports, making these Rules immediately enforceable rather than aspirational.[337]

- *GOBARdhan Scheme:* This program, which stands for Galvanizing Organic Bio-Agro Resources, aims to convert animal dung and other organic waste into biogas/bio-CNG and organic manure. This directly diverts organic waste from dumpsites and creates a circular economy.

- *Waste-to-Energy and Biogas Plants:* The promotion of projects that convert segregated organic waste into energy (biogas, RDF, etc.) is a key strategy for both waste management and methane mitigation.

SBM 2.0 (Urban) – Lakshya Zero Dumpsite (2025–26) Under SBM-U 2.0, the Government of India has set the **Lakshya Zero Dumpsite** target, requiring all urban local bodies (ULBs) to remediate legacy dumpsites by **2025–26.** This involves biomining and bioremediation to recover land, reduce leachate and odour, and cut uncontrolled methane emissions.

Moreover, **DRAP provides enabling support** to achieve the national target of *"Lakshya Zero Dumpsites"* by remediating over 8.8 crore MT of legacy waste, accounting for nearly 80% of the remaining dumpsite load. DRAP adopts a mission-mode approach with dedicated financial support of ₹550 per tonne, a robust monitoring mechanism, and a "5-P" framework emphasizing political leadership, public finance, partnerships, project management, and public advocacy. Beyond waste clearance, the programme envisions transforming reclaimed landfill land for productive urban use—such as green spaces, solar parks, or infrastructure—while contributing significantly to methane mitigation, circular economy goals, and improved urban environmental quality.

Garbage Free Cities by 2026 – 100% Segregation and Processing: SBM-U 2.0 also sets the **Garbage Free Cities** vision, with a time-bound target of achieving **100% door-to-door collection, 100% source segregation, and 100% scientific processing of waste by 2026.** The intent is to eliminate untreated waste flowing into dumpsites altogether, embedding segregation and decentralised processing as the operational baseline.

SWM Rules, 2026 – Scientific Closure of Landfills: The SWM Rules, 2026, consistent with 2016 Rules, mandate that legacy dumpsites must either be biomined or closed scientifically, and that new landfills must be scientifically engineered. Closure in this context means contouring, capping with soil layers, installation of gas vents, and leachate management systems to prevent fire outbreaks and methane release. The rules made closure legally binding, and the National Green Tribunal and the Supreme Court has reinforced compliance through repeated directives.[338]

GOBARdhan Scheme (2018 onwards): Launched in **2018**, the Galvanizing Organic Bio-Agro Resources (GOBARdhan) programme focuses on converting animal dung and organic waste into biogas, bio-CNG, and organic manure. The scheme supports the national waste processing agenda by diverting the organic fraction away from landfills while creating renewable energy and soil nutrients.[339]

Waste-to-Energy and Biogas Expansion – SATAT (2025): The Indian government does not have a defined "waste to energy" target but promotes it under broader renewable energy and waste management goals, such as achieving 500 GW of non-fossil fuel capacity by 2030 and establishing 5000 BioCNG plants by 2023-24 under the SATAT initiative. The Ministry of New and Renewable Energy (MNRE) supports WtE projects through the National Bioenergy Programme, which offers financial assistance and revised guidelines to encourage project development and implementation from FY 2021-22 to 2025-26. The Government's **SATAT scheme (2018)** sets a target of **5,000 compressed biogas plants by 2025.** In parallel, SBM-U 2.0 promotes large-scale biogas and waste-to-energy projects to manage the organic and combustible fraction of municipal waste. This directly reduces the load on landfills while building renewable energy supply.

Extended Producer Responsibility (EPR) – Phased Targets from 2022: The **Plastic Waste Management (Amendment) Rules, 2022** and the **E-Waste (Management) Rules, 2022** introduced annual EPR targets, phased in from 2022 onwards, requiring producers to ensure collection and recycling of plastics, packaging, and electronic waste. These rules aim to systematically cut recyclable and hazardous waste entering landfills.[340]

Construction and Demolition Waste Rules, 2016: The **C&D Waste Management Rules, 2016** require ULBs to establish dedicated facilities for recycling construction debris and to promote use of recycled aggregates in roads and buildings. While not tied to a single national deadline, the benchmark is universal coverage across all ULBs, ensuring inert waste does not overwhelm landfills.[341]

Hazardous and Biomedical Waste Regulations (2016): The **Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016** and the Biomedical Waste Management Rules, 2016 establish strict segregation, transport, and treatment requirements for hazardous and biomedical waste. These prevent toxic and infectious material from entering municipal landfills.[342]

Considering the intricate policy landscape as outlined above, and the state of waste management as detailed in the report; this study posits two roadmaps that can help India achieve effective solutions for its waste and emissions challenges in future. These roadmaps have some similar touchpoints but vary in the nuances of some policies and the ways of implementation – especially considering the country's wide landscape that can present region-specific challenges as well.

Roadmap 1 focuses on rectifying the environmental mistakes of the past by **tackling existing dumpsites,** employing techniques like **Biomining** (excavating and separating old waste, often followed by bioremediation to restore soil) or **Biocapping** (scientifically sealing the land) and **LFG capture** for methane utilization. This critical work leads to the eventual goal of **retaining and repurposing valuable land.** Conversely, **Roadmap 2** is a forward-looking strategy that aims to ensure **minimal waste reaches landfills in the future** by demanding rigorous **source segregation** and direct diversion to specialized processing facilities. Here, waste is channeled based on composition for **recycling, composting, incineration, or Waste-to-Energy (WtE)** conversion, thereby maximizing resource recovery and establishing a sustainable, circular economy model.

Roadmap I: Closing Existing Dumpsites addresses one of the most urgent gaps in India's waste sector: the millions of tonnes of untreated waste sitting in legacy landfills. These sites are the largest single contributors to uncontrolled methane emissions, leachate contamination, and recurring landfill fires, while also locking up valuable urban land. Their closure is critical both to reducing climate and health

4.3 Roadmap I: Pathway to Closing Existing Dumpsites

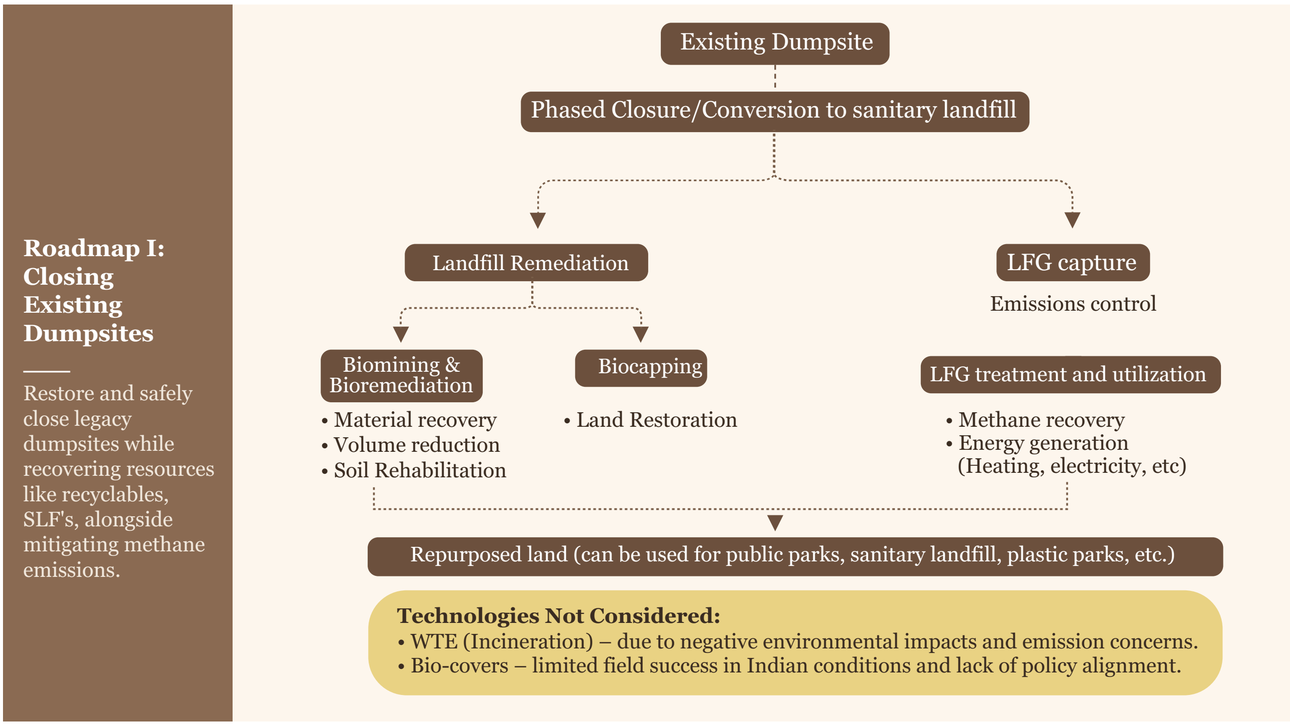


Figure 31: Closing existing dumpsites and landfills

risks, and to enabling Indian cities to transition toward a zero-landfill future.

The roadmap proposes a phased closure strategy in which unmanaged dumpsites are converted into engineered sanitary landfills. This is achieved through two primary pathways. First, **biomining** enables large-scale material recovery and volume reduction, followed by bioremediation and biocapping to restore soil and land quality. Second, **landfill gas (LFG) capture and utilization** ensures that methane is neutralized during and after remediation, either through safe flaring or by converting it into usable energy such as electricity or compressed biogas (CBG). Together, these approaches stabilize dumpsites, mitigate emissions, and prepare land for safe repurposing.

Note: Certain technologies have been excluded from this roadmap.

1. **Waste-to-Energy (WtE) incineration:** While technically capable of reducing waste volumes, incineration has been excluded due to its high emission profile, poor environmental performance in Indian conditions, and repeated evidence of regulatory and operational failures. Incinerators have struggled with mixed, low-calorific waste, leading to incomplete combustion, toxic air pollution, and high financial costs without meaningful methane mitigation benefits.
2. **Bio-covers:** Although bio-covers can reduce methane emissions by oxidizing methane into CO_2 through microbial activity, their success in Indian field conditions has been very limited. Issues such as highly heterogeneous waste, high rainfall variability, and lack of a strong policy framework for monitoring and maintenance have prevented scale-up. Given these constraints, bio-covers do not currently align with India's regulatory priorities and are not emphasized in this roadmap.

4.3.1. Landfill Gas (LFG) to Energy

Unmanaged legacy landfills remain a major source of methane emissions in India. The absence of landfill gas capture systems results in uncontrolled methane releases, frequent fires, and significant environmental, health, and safety risks. Most ULBs undertake biomining without prior gas profiling or fire prevention planning, leaving a significant share of methane emissions unaddressed. Given the slow pace of biomining nationally, interim landfill gas management must precede and operate alongside remediation.

The most immediate intervention is the deployment of gas extraction and flaring systems, which can neutralize methane before excavation begins. Where gas yields are higher and stable, utilization pathways such as electricity generation, compressed biogas

(CBG), or industrial heat become viable. The roadmap therefore calls for a phased approach: initiate gas mapping and venting for fire prevention, progress to flaring or utilization systems based on site economics and finally transition into full-scale biomining once the site is stabilized. Capturing landfill methane in this way provides both immediate safety benefits and a critical pathway for climate mitigation.

The rules mandate landfill gas control and collection systems at ALL NEW sanitary landfills (Schedule II, Criteria F). Gas must be used for thermal applications or power generation where viable, or flared. Passive venting is only permitted if utilisation or flaring is not possible.

Table 30: Landfill gas to energy: challenges and solutions

Challenge	Solution
Internal contradiction in the 2026 rules: LFG mandate vs. segregation mandate. Rules require gas capture at new sanitary landfills, but also mandate four-stream segregation so only inerts reach landfills. Inerts have no biomethane potential — the two provisions are mutually inconsistent.	LFG capture provisions should be explicitly scoped to legacy dump sites with high organic content where capping has been undertaken — not mandated as a universal requirement for new scientific landfills receiving only inert residuals. A regulatory clarification should explicitly state that gas recovery infrastructure is required at: (a) legacy dump sites being capped or partially capped, and (b) new landfills only in transitional period while mixed waste is still being received. New scientific landfills receiving only inerts are exempt from gas collection mandates.
Measurement methodology mismatch. Current emission estimates diverge 60-fold across methodologies. IPCC models calibrated to US/European waste compositions systematically underestimate emissions from Indian high-moisture, high-organic waste streams.	Develop and mandate India-specific methane emission factors calibrated to domestic waste compositions, moisture content, and temperature profiles. Commission IIT/NEERI-led field studies across representative Indian landfill types to establish a validated national emission factor dataset. Replace IPCC Tier 1 defaults for Indian compliance reporting within 24 months of rules notification.
Lack of methane detection & monitoring Most landfills lack reliable systems to locate methane pockets, detect leaks, or plan efficient capture.	Deploy portable methane sensors, drone-based thermal imaging, and satellite surveys to map plumes. Use these maps to guide well placement and venting infrastructure. Integrate monitoring data into landfill operations to enable faster, targeted responses and fire prevention.
Legacy dumps lack basic infrastructure Older, open dumps without liners or wells release methane freely, causing uncontrolled emissions and fires.	Retrofit legacy sites with vertical/horizontal gas wells during biomining or closure. For open dumps, install basic active collection systems with flaring; for capped sites, install modular extraction networks for flaring or utilization (CBG, power, industrial heat). Passive venting only if recovery and flaring are infeasible.
High CAPEX, uncertain yields, low tariffs Projects need large capital but methane flows are variable and tariffs unattractive, limiting investor confidence.	Introduce VGF/subsidies for LFG capture systems. Bundle LFG with composting/biomining in integrated contracts to spread costs. Use carbon finance to monetize methane reductions and strengthen project viability.
Weak enforcement & coordination SWM Rules (2026) mention gas capture but have no timelines, targets, or inter-agency clarity, leading to poor implementation.	Launch a mission-mode programme for LFG, with phased national targets, technical guidelines, penalties for inaction, and rewards for early adopters. Integrate landfill methane mitigation into city-level climate action plans.
Energy utilization barriers Power plants face grid delays, variable methane flows, and lack of offtake agreements.	Use LFG for captive power at landfill facilities (e.g., weighbridges, STPs) or purify into CBG for transport/industrial use. Simplify grid access and design favorable tariff mechanisms to improve uptake.

Table 31: Landfill gas to energy: policy tweaks and enablers

Policy Tweaks	Enablers
▪ **Clarify LFG mandate scope in rules: issue MoEFCC/CPCB circular explicitly stating that gas capture provisions apply to legacy dump sites with organic content being capped, NOT to new sanitary landfills receiving only inert residuals post-segregation. (National mandate for active gas management at all dumps >10 years old.)Tariff & carbon incentives:** Notify feed-in tariffs for LFG/CBG and fast-track carbon credit registration under India's registry. ▪ **Recognize LFG as renewable:** Classify LFG as "must-run" renewable under RPO; mandate DISCOMs to procure a share of LFG power. ▪ **Risk index & fund:** Develop a Methane Risk Index (MRI) to prioritize sites and establish a Landfill Methane Extraction & Utilization Fund (LMEUF) for capital support.	▪ **Gas-specific SOPs for legacy dump site operators: develop and distribute standardized protocols for gas profiling before biomining commencement, gas well installation during capping, and fire prevention during active remediation. Many ULBs commence biomining without any gas assessment.** ▪ **Central funding support:** SBM-U 2.0 and AMRUT to explicitly cover gas wells, flares, and modular recovery systems. **Blended finance tools:** Viability Gap Funding, climate funds, green bonds, and guarantees to de-risk projects. ▪ **Carbon finance readiness:** Establish standardized MRV protocols to quantify methane reductions and unlock credits. ▪ **Institutional coordination:** MoHUA and CPCB to lead central dashboards, enforce timelines, and reward progress via Swachh Survekshan and NDC tracking. ▪ **Market linkages:** Standardized PPAs, integration into SATAT for CBG, and tie-ups with City Gas Distribution networks. ▪ **Technical partnerships:** Engage NEERI, IITs, and accredited firms for design, audits, and supervision. ▪ **Data transparency:** Centralized dashboards (linked to NWDXP) to track gas capture, flare uptime, and verified GHG reductions.

4.3.2. Bio-Capping + Bio-Mining + Landfill Reclamation

Legacy dumpsites are one of the biggest obstacles to sustainable waste management in India. While biomining has been scaled across many cities, it often proceeds without complementary safeguards or market linkages, leading to recontamination, stranded outputs, and limited climate impact. To close dumpsites effectively and permanently, biomining must be integrated with strict diversion controls, guaranteed end-use markets, and credible emissions accounting. Bio-capping and bioremediation, when aligned with these measures, not only stabilize land but also enable its safe reclamation and future use.

This section outlines the key challenges and solutions, along with enabling policy and institutional reforms required to embed biomining and reclamation as central pillars of India's landfill closure roadmap.

Rule 15 now mandates that all legacy dumpsites be geographically mapped and assessed by 31 October 2026. Local bodies must prepare time-bound action plans for bio-mining and bioremediation and upload quarterly progress on the centralised portal. Fresh waste disposal at sites under remediation is explicitly banned (Rule 15(7)). SPCBs must undertake annual audits of bio-mining progress. Screened fraction utilisation plans must be documented before disposal.

Table 32: Bio-capping and bio-mining: challenges and solutions

Challenge	Solution
Lack of standardized MRV systems for emissions reduction → ULBs cannot credibly account for avoided methane, limiting access to climate finance and carbon markets.	**Develop standardized MRV frameworks** for biomining, including landfill methane calculators, third-party audits, and integration with India's emerging carbon market. Create toolkits and capacity-building programs for ULBs and contractors.
No regulatory guidance on capping vs. bio-mining decision. For very large sites, full bio-mining may be neither safe nor practical. Internal pressure dynamics, leachate under pressure, and structurally compromised waste bodies can make excavation hazardous. The 2026 rules do not provide a site-assessment framework for this determination.	CPCB should issue supplementary guidelines providing a decision framework for site assessors to choose between scientific capping and active bio-mining based on: (a) waste volume and dump height, (b) structural stability assessment, (c) gas pressure dynamics, (d) available land for replacement infrastructure, and (e) proximity of RDF/inert offtake markets. Sites exceeding defined thresholds (e.g., >50 metres height, >1 crore MT) should be presumed capping candidates unless a specific safety case for bio-mining is submitted to SPCB.

Challenge	Solution
Contractor quality and accountability gap at small and medium sites: Bio-mining contracts at smaller sites are vulnerable to shortcuts: contractors excavating material and relocating it to low-lying areas without processing, bioremediation, or quality testing. In documented cases, the same waste has been weighed multiple times in a single transaction.	SPCB annual audit requirement (Rule 15(10)) is necessary but insufficient. Supplement with: (a) mandatory third-party weighment verification with tamper-evident digital records uploaded to the centralised portal in real-time; (b) geo-tagged GPS tracking of all waste transport vehicles from site to processing/ disposal destination; (c) output fraction quality certificates issued by accredited labs before any fraction is signed off for disposal or reuse; (d) performance bonds linked to verified output quality, not just tonnage processed. The Greater Chennai Corporation model — where inert offtake requirements are embedded directly in the bio-mining RFP — should be mandated as a national standard for all bio-mining contract design.
National flat bio-mining rate ignores geographic logistics realities. SBM's ₹550/ tonne benchmark does not account for distance to cement plants or disposal facilities. A project near multiple cement plants may be viable at ₹700-800/tonne; the same project in Guwahati may require ₹1,400+/tonne. Contractors accepting below-cost contracts are structurally forced into shortcuts.	Mandate use of the government-developed location-specific bio-mining cost toolkit (which calculates costs based on diesel prices, minimum wages, and distance to cement plants) for all new bio-mining contracts. No bio-mining contract should be awarded at a rate below the toolkit's location-specific estimate. SBM funding should cover the location-specific cost rather than a national average. State-level RDF market mapping should be completed before bio-mining targets are set in each state.

Table 33: Bio-capping and bio-mining: policy tweaks and enablers

Policy Tweaks	Enablers
▪ **MoEFCC & MoHUA Circular:** Classify RDF/fines as approved co-processing materials; mandate inclusion in CPWD/NHAI Schedule of Rates. ▪ **SBM-U Guidelines:** Require verified end-user agreements before funding release; introduce targeted subsidies for logistics/transport. ▪ **Standardize MRV:** Issue annexure defining approved landfill MRV methodologies; mandate audits and link reporting to ICM registry. ▪ **Mandate location-specific bio-mining costing:** no contract to be awarded below the government toolkit's location-specific cost estimate. SBM funding to cover the full location-specific cost, not a national flat rate. ▪ **Issue CPCB supplementary guidelines for capping vs. bio-mining decision:** site-assessment criteria determining when capping is safer and more appropriate than active excavation for large legacy sites.	▪ **Waste Diversion Monitoring Dashboard:** GPS-based tracking of vehicle routes, geo-tagged diversion points, and citizen hotlines. ▪ **Remediation Resource Exchange Platform:** Centralized digital marketplace to link ULB outputs with verified buyers, ensuring traceability and pricing intelligence. ▪ **Capacity Building:** Regular training for ULBs, contractors, and informal sector integration on MRV, diversion enforcement, and logistics. ▪ **Carbon Finance Access:** Fast-track compliant ULBs into Article 6.2-linked pilots; tie incentives to verified methane reduction outcomes. **Cluster-based model for small and medium sites:** cluster approach, aggregating nearby small dump sites under centralised processing facilities to improve contractor economics and quality control. DRAP-style structured programmatic support for the 3,200+ sites outside DRAP's current scope. **Real-time third-party weighment verification:** tamper-evident digital records with GPS-tagged transport vehicles, uploaded to portal in real-time, to eliminate repeat-weighment fraud at small sites.

4.4 Roadmap II: Pathway to No Future Dumpsites

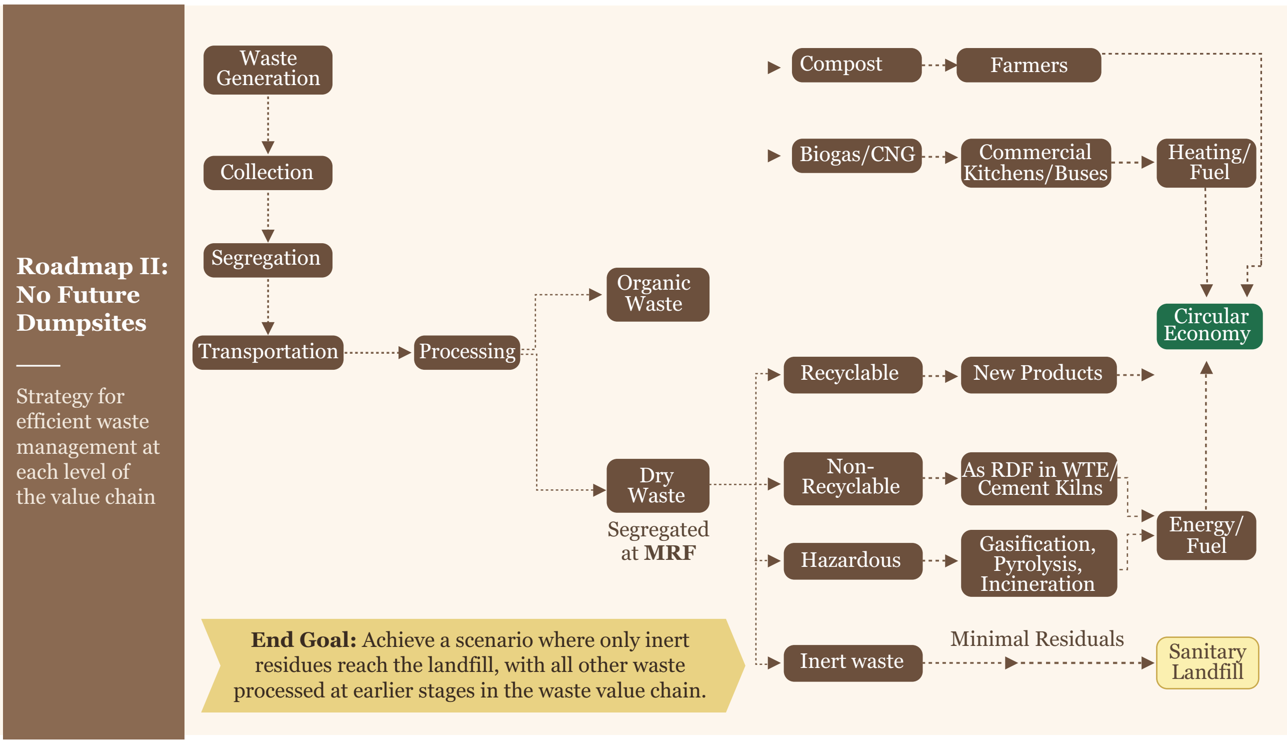


Figure 32: Preventing future dumpsites through the waste value chain optimisation

Roadmap II lays down a forward-looking strategy to ensure that India does not create new unsanitary dumpsites, moving instead towards a system where only inert residues are landfilled, in alignment with the vision and objective of new Solid Waste Management Rules 2026 and the accompanying Dumpsite Remediation Accelerator Program (DRAP). Further, this design aligns closely with the government's "Garbage Free Cities" vision under Swachh Bharat Mission–Urban 2.0, which mandates 100% segregation and scientific processing, as well as with national targets for biomethanation, composting, and recycling.

The roadmap begins with segregation at source, supported by structured collection and transportation systems. From there, waste is directed into specialized processing streams that emphasize both environmental safety and resource efficiency.

Organic waste is transformed into compost for farmers or biogas/CBG for transport, heating, and industrial applications. Dry waste, sorted at MRFs, is channelled into recycling industries, RDF for cement kilns and energy plants, or safe destruction pathways for hazardous fractions. Finally, only inert residues reach engineered sanitary landfills, which act as controlled end-of-pipe solutions.

By systematically diverting recoverable materials into productive use, this roadmap directly supports India's transition to a circular economy, where waste becomes an input for agriculture, energy, and manufacturing rather than an environmental liability. It also ensures alignment with key government missions like SBM-U 2.0, Waste to Wealth Mission, and SATAT, which collectively push cities to integrate waste processing, renewable energy generation, and decentralized infrastructure. Additionally, the circular economy model has been noted as foundational to sustainable industrial growth and transformation , and the government formed 11 committees, led by the concerned line ministries and comprising officials from MoEFCC and NITI Aayog, domain experts, academics and industry representatives to prepare comprehensive action plans for transitioning from a linear to a circular economy in their respective focus areas.

The end goal is a future where municipal systems eliminate uncontrolled dumping, safeguard public health, and maximize resource recovery. By embedding circular economy pathways into each stage of the chain, Roadmap II prevents the recurrence of legacy dumpsites and positions waste management as a driver of climate, economic, and social gains.

4.4.1. Behavioral Intervention: Prioritizing Reduction of Organic Waste at Source – Generating Waste Responsibly

Introduction

A large share of India's municipal solid waste—50–60%—is organic, mostly food and kitchen scraps. When this ends up in landfills, it decomposes anaerobically and releases methane. Despite this, waste policy and ULB action plans rarely include behavioral strategies to cut food waste or promote source-level composting. Reducing organics at source is essential: every ton diverted prevents methane release, reduces landfill loads, and supports a circular economy by turning waste into compost or biogas.

Table 34: Reduction of organic waste at source: challenges and solutions

Challenge	Solution
High organic waste load in landfills drives methane emissions. Poor segregation and limited decentralized options mean most biodegradable waste ends up in dumps, fueling methane release and landfill fires. Meanwhile, the quantum of waste generation is rising, particularly food waste.	**Community-led reduction and diversion of organic waste.** Implement campaigns targeting households, markets, eateries, and institutions to: (i) reduce food waste generation, (ii) segregate waste at source, and (iii) compost at household or community level. Tools include citizen champions, incentive-based segregation contests, school curriculum integration, and public messaging that links food waste to climate harm. Research shows that local leadership, social norms, and enforcement measures are effective. However, penalties alone are unlikely to work without reliable collection services, and stronger citizen demand for segregated collection remains an underused driver of change.

Table 35: Reduction of organic waste at source: policy tweaks and enablers

Policy Tweaks	Enablers
Mandate ULBs to Quantify and Strategize organic waste minimization at source While the SWM Rules 2026 require ULBs to create public awareness throughAmend municipal action plans to include targets for organic waste reduction. Require household composting where feasible. Incentivize bulk generators (hotels, hostels, markets) to set up on-site composting. Integrate behavior-change metrics (e.g., % reduction at source) into ULB performance assessments. Embed measures into SBM-U 2.0 and Smart Cities guidelines.	▪ **Climate messaging and digital nudges:** Use simple storytelling (e.g., "rotting food heats the planet") to connect citizens to the climate impact of food waste. Deploy nudging tools like composting reminder apps, gamified zero-waste apps, or QR codes at drop-off points. ▪ **Community anchors:** Involve RWAs and local committees as behavioral anchors in both middle-class and informal urban areas. Engage local leaders who shape community perspectives like Panchayat members. **Capacity building:** Train citizen volunteers, SHGs, and youth groups to run workshops and peer-learning campaigns. ▪ **Incentives and Penalties:** Use property tax rebates, user-fee discounts, or green certifications for households and RWAs demonstrating high levels of source reduction and composting. Operationalize the penalty mechanism under the SWM Rules, 2016 through consistent monitoring and effective compliance enforcement.

4.4.2. Segregation at Source and Sustenance Across the Value Chain Introduction

Source segregation is the foundation of effective waste management. The quality of every downstream process, from composting and biomethanation to recycling and safe disposal, depends directly on how cleanly waste is separated at the point of generation. The Solid Waste Management Rules, 2026 mandate a shift from the earlier three-stream system to a four-stream segregation model *(Wet, Dry, Sanitary, and Special Care Waste)* placing binding obligations on generators, collectors, and local bodies to ensure waste remains segregated from the point of generation through collection, transport, and delivery to processing facilities. Optimizing segregation through decentralization, advanced monitoring, and community participation is essential to build resilient city-level systems, reduce transportation burdens, and ensure maximum material recovery. This roadmap section focuses on strengthening compliance with the four-stream mandate, maintaining segregation integrity across the collection chain, and using infrastructure, incentives, and community systems to embed segregation as a behavioral norm.

Table 36: Segregation at source: challenges and solutions

Challenge	Solution
Dependence on large, centralized facilities and landfills. Cities rely heavily on centralized plants, creating logistical inefficiencies and bottlenecks.	**Promote decentralized systems.** Establish localized waste processing units at ward/zonal level or within large complexes. Source segregation becomes foundational, supported by RWAs and bulk waste generators. Decentralization reduces pressure on centralized plants, lowers transport emissions, empowers communities, and increases resource recovery at the local level.
Waste sorted at source is mixed during collection, eroding public trust. The increased requirement of four-stream segregation mandate under SWM Rules 2026 risks producing segregation on paper only.	The 2026 Rules' compliance schedules should be explicitly linked: no penalty for non-segregation at source without verified collection system compliance; no processing facility registration without confirmed feedstock supply agreements.
Low compliance, behavioral inertia, and infrastructure gaps. Despite SWM Rules (2016) mandating three-stream segregation, compliance remains low due to behavioral habits, weak enforcement, lack of bins, and under-utilization of informal sector knowledge.	**Adopt advanced collection and monitoring systems.** Deploy digital tools that provide real-time data on waste types and volumes, offer user feedback, and enable data-driven enforcement. **Set up decentralized automated MRFs.** Use conveyor belts, AI sorting, and compact local facilities to refine segregation quality, reduce transport costs, and improve worker safety. Automated systems enhance throughput and recycling market value.

Table 37: Segregation at source: policy tweaks and enablers

Policy Tweaks	Enablers
Formalize community waste champions: Create a trained, certified "Community Waste Management Cadre" under SBM/urban missions, funded by ULBs. **Timeline Optimization:** A joint segregation-processing compliance calendar developed at state- or local-levels, reviewed annually by CPCB, to ensure sustenance of segregated output till it reaches different processing points as feedstock.	▪ **Performance-linked funding:** Tie ULB funding to measurable improvements in segregation rates. ▪ **Skill development:** Launch specialized training for operation/maintenance of advanced segregation systems. ▪ **Waste-to-credit systems:** Reward communities and integrate informal workers through digital credit mechanisms, providing income and traceability. ▪ **Impact Investment & Technology Adoption Funds:** Finance automation, digital platforms, and social enterprises scaling segregation models. ▪ **Innovation Challenges:** Promote next-gen circular economy technologies for complex waste streams. ▪ **Community-led programs:** Integrate informal workers formally, empower RWAs and local champions for behavioral change, and use their networks to strengthen compliance.

4.4.3 Waste Collection Modernization

Introduction

Collection is themost visible link in the waste management chain, and inefficiencies here ripple across the entire system. Unmonitored fleets, static routes, and irregular schedules lead to missed pickups, excess fuel use, and early decomposition of waste in community bins, which increases methane risk even before it reaches landfills. Modernizing collection systems with smart technologies is therefore a critical enabler for Roadmap II, ensuring efficiency, accountability, and measurable progress toward zero-dumpsite and methane reduction goals.

Table 38: Waste collection modernisation: challenges and solutions

Challenge	Solution
Inefficient, unmonitored, and irregular collection operations. Vehicles follow static, non-optimized routes, causing delays, excess fuel use, and missed bins. Aging fleets add to breakdowns and service gaps.	**Micro-planning at the lane level** should be the operational model of choice. This includes tailoring routes, timing, and vehicle types to local settlement patterns, particularly context-specific stream models for smaller, remote, and/or rural systems can prove to be effective. This can be supported through technology; **equipping primary and secondary collection vehicles with smart systems** can improve efficiency. Examples include GPS, IoT-based sensors, and AI to track location, speed, bin-lift events, and fuel use in real time, vehicles linked to RFID-tagged or smart bins with fill-level alerts. There exists already demonstrated scale in India, with 9,000+ GPS/RFID-enabled vehicles in 66+ Smart Cities.[343]

Table 39: Waste collection modernisation: policy tweaks and enablers

Policy Tweaks	Enablers
▪ **Amend SWM Rules, 2026:** Introducing verification through digital logs and random audits, alongside existing reporting and compliance requirements under Chapter II, Section 8, would strengthen monitoring, traceability, and accountability. ▪ **Update SBM-U 2.0 guidelines:** Add compliance checklists for digital enablement in vehicle procurement and contractor onboarding.	▪ **Digital Performance Audit Mandate and Performance Linked Payments:** Payments to contractors and ULB operators linked to automated verification of KPIs such as route adherence, bin-level service confirmation, and on-time collection. ▪ **Institutional Capacity Building:** Dedicated training and capacity-building initiatives for local bodies responsible for waste management, facilitated through institutions such as NIUA and Swachhata Knowledge Partners (SKPs), can strengthen technical expertise and support more **effective micro-planning.** ▪ **Transparency & risk reduction:** Automated monitoring minimizes subjectivity in payments, reduces waste stagnation, and lowers risks of odor, vector breeding, and premature methane release.

4.4.4. Sustainable Transportation of Waste

Introduction

Transportation is a critical but resource-intensive stage in the waste value chain. In India, long hauls to landfills and processing plants, static route planning, and congestion make waste transport costly, polluting, and unreliable. These inefficiencies not only raise fuel and O&M costs but also prolong the time waste remains in community bins, accelerating odor, nuisance, and decomposition risks. Strengthening logistics through smarter models and technology is therefore essential to improve efficiency, reduce emissions, and stabilize operations.

Table 40: Waste collection modernisation: policy tweaks and enablers

Challenge	Solution
Inefficient, costly, and polluting transportation. Waste often travels long distances through congested routes, increasing operational costs, fuel use, and carbon emissions.	**Adopt hub-and-spoke logistics.** Establish transfer stations where smaller vehicles offload into larger long-haul trucks, reducing vehicle kilometers traveled and fuel demand. Real-time monitoring of transfer station capacity helps prevent bottlenecks.
Static routing, fuel inefficiency, and delayed waste transit. Routes are manually designed, ignoring traffic, bin fill-levels, or road conditions. This prolongs transit, causes inconsistent coverage, and increases decomposition risks.	**Introduce dynamic, intelligent routing tools.** AI-based systems can adapt routes daily, balancing workloads, cutting fuel consumption, and improving service in dense areas.

Table 41: Sustainable transportation of waste: policy tweaks and enablers

Policy Tweaks	Enablers
▪ **Enable Inter-ULB Transfer Agreements:** State urban departments to facilitate smaller ULBs sending waste to larger hubs, supported by viability gap funding (VGF). ▪ **National Urban Waste Logistics Standard:** Draft MoHUA guidelines mandating intelligent routing tools in Class I ULBs, phased in metros and million-plus cities within 3 years, tied to funding eligibility.	▪ **Mandated Regional Waste Transfer Hubs:** SWM Rules, 2026 provide for transfer stations as a bridge between collection and processing with bulk transportation. Effective implementation of this can reduce transportation induced inefficiency. ▪ **Impact Investment Fund for Waste Logistics:** Backed by AIM and NITI Aayog to finance startups offering hyper-local route optimization. ▪ **Waste Logistics Innovation Hubs:** MoHUA and MeITY to set up sandboxes in Smart Cities for testing and scaling AI-driven routing models.

Organic waste processing

4.4.5. Wet Waste – Composting

Introduction

Composting is the most direct and scalable pathway to manage India's high share of biodegradable waste, which makes up 40–60% of urban MSW. By diverting organics away from landfills, it not only reduces methane emissions but also produces nutrient-rich compost that supports soil health and circular economy goals. However, uptake remains uneven, with centralized plants facing feedstock contamination and weak markets, decentralized sites constrained by space and training, and home composting hampered by behavioral hesitancy. Addressing these challenges through targeted solutions, policy tweaks, and enabling mechanisms is essential for creating a viable composting ecosystem.

Table 42: Wet waste composting: challenges and solutions

Challenge	Solution
Centralized Composting: Poor segregation and weak market linkages reduce compost quality, increase residues, and undermine financial viability.	Strengthen segregation through incentives/penalties, integrate pre-processing (trommels, shredders, sorters), and establish compost certification in alignment with FCO Standards.[344] ULBs should link output to institutional buyers (agriculture, cooperatives, greening agencies).
Decentralized Composting: Space constraints, poor maintenance, odor issues, and high capital costs limit adoption in dense residential areas.	Reserve ward-level land for compost hubs as required under SWM Rules 2026 (cities >1M to allocate 0.5% land). Ensure implementation of BWG responsibilities under the new Rules 2026 to compost on-site. Train staff under DAY-NULM, and provide capital support via SBM-U 2.0/CSR. Link performance to property tax rebates or user fee discounts. Mandate impermeable bases and leachate management per Schedule III technical standards.
Home Composting: Low uptake due to odor, pest fears, and lack of kits/training; resistance especially in high-rises.	Run NGO/RWA-led workshops, demos, and mentorship programs; provide subsidized compost kits; designate shared composting zones in housing complexes as under SWM Rules 2026 mandate for gated communities and institutions (>5,000 m2). Incentivize adoption through rebates and recognition models. Certify RWAs for green performance under Swachh Survekshan.

Table 43: Wet waste composting: policy tweaks and enablers

Policy Tweaks	Enablers
▪ **Mandatory Segregation Audits:** Amend SWM Rules, 2026 to require RWAs and bulk generators to undergo periodic audits tied to Swachh Survekshan scoring. ▪ **Formal Offtake Agreements:** SBM-U 2.0 to promote MoUs with state/para-statal departments; compost to be included in procurement for AMRUT 2.0 and urban greening. Department of Fertilizers can enforce co-marketing ratio (e.g., 3–4 bags compost per 6–7 bags chemical fertilizer). ▪ **Decentralized Infrastructure Mandate:** Cities >1M population to allocate 0.5% land for compost hubs; bye-laws to mandate composting zones and annual training plans. ULBs to phase out chemical fertilizers in public parks in favour of compost per SWM Rules 2026. ▪ **Home Composting Promotion:** Introduce rebates/utility discounts for households achieving >80% composting; update building codes to include composting provisions; certify RWAs for green performance under Swachh Survekshan. ▪ **Quality Testing Infrastructure:** Department of Agriculture & Farmers Welfare to operationalize district-level compost quality labs or empanel third parties by 30 September 2026 as required under SWM Rules 2026.	▪ **Compost Market Integration Platform:** Supported by the data and information receivable through digital reporting requirements under the new rules, a digital exchange may be set up. Linkage to organic farming subsidies, PM-PRANAM incentives, CSR, and SBM-U 2.0 market development assistance may be made. ▪ **Community Engagement & Training:** RWAs, NGOs, and citizen champions to normalize composting and ensure operational quality. ULBs mandated to run public awareness campaigns for home composting, vermi-composting, and community-level composting per SWM Rules 2026. ▪ **Innovation Support:** Launch city-level innovation challenges to scale low-cost kits, odor-control systems, and compact composting solutions tailored to dense housing. Incentives (market development assistance, tax benefits) to entities implementing on-site wet waste treatment under SWM Rules 2026. Link outcomes to PM-PRANAM and organic farming incentives. ▪ **Near-Market Composting Infrastructure:** Establish decentralised compost plants at or near vegetable, fruit, flower, and meat markets as directed under SWM Rules 2026 to ensure hygienic waste management and short supply chains.

4.4.6. Biogas and Bio-Methanation

Introduction

Biogas production (biomethanation) is a cornerstone technology for managing India's organic waste stream, which makes up more than half of total municipal solid waste. By capturing methane through anaerobic digestion and upgrading it to Bio-CNG or electricity, this process addresses landfill methane emissions, supports renewable energy targets, and produces nutrient-rich digestate for agriculture. The Indore 550 TPD Bio-CNG plant illustrates the potential of large-scale systems when well-managed, creating a circular economy pathway by turning waste into energy and fertilizer. However, challenges persist across plant sizes, financing, market linkages, and technical operations, requiring both structural reforms and enabling interventions.

Additionally, methane emissions associated with organic solid waste can be reduced to near-zero levels through anaerobic digestion, particularly when supported by effective Leak Detection and Repair (LDAR) systems. This offers a lower-emission alternative to composting and landfilling, both of which have been reported to generate methane emissions within the sector.

Table 44: Biogas and bio-methanation: challenges and solutions

Challenge	Solution
Small- & Medium-Scale Plants: Frequent shutdowns due to poor training, faulty construction, water scarcity, and weak after-sales service.	Provide structured training modules, standardized construction protocols, reliable after-sales contracts, and water-efficient digester technologies. Use refresher trainings, third-party audits, and manufacturer-backed service guarantees to sustain performance.
Large-Scale CBG Plants: Inconsistent feedstock due to weak segregation and unreliable supply chains.	Strengthen source segregation and feedstock access as required and promoted under SWM Rules 2026; secure long-term bulk-waste agreements with hotels, mandis, and canteens; allow operators to participate in collection logistics to reduce costs and stabilize feedstock.
Financial Viability: High upfront costs, long payback periods, and investor skepticism.	Introduce assured offtake (5% procurement mandate), price support schemes, carbon finance, and blended finance. Offer credit guarantees and concessional loans to reduce risk. MoPNG to facilitate biogas buyout and ensure pipeline connectivity for CBG offtake, through a dedicated coordination mechanism, with periodic monitoring and grievance redressal.
Digestate Utilization: Narrow policy definition limits use to Fermented Organic Manure, excluding other applications.	Department of Agriculture & Farmers Welfare is supposed update standards for use of FOM and LFOM from biomethanation facilities by 30 June 2026 per SWM Rules 2026. These standards should to allow safe use in soil remediation, landscaping, and bio-based products enabling expansion of markets to diversify revenue streams for operators.
Skilled Workforce Shortage: Lack of engineers, microbiologists, and trained operators leads to inefficiencies.	Develop specialized training programs, certification courses, and industry-academia partnerships with support of MNRE, NIUA, Chambers of Commerce, etc. Establish regional centers of excellence and knowledge-sharing platforms.
Methane Leakage: Poor design and leak detection result in 0.5–15% methane loss, undermining climate benefits.	Mandate LDAR protocols, use leak-proof digesters, and adopt SCADA/IoT-based monitoring. Train operators in leak detection and require third-party audits for accountability. Standards and protocols developed or being developed by regulators must have these provisions; e.g., the standard environmental norms for CBG plants to be set up by CPCB per SWM Rules 2026.

Table 45: Biogas and bio-methanation: policy tweaks and enablers

Policy Tweaks	Enablers
▪ **Mandate enforcement and traceable supply:** Enforce SWM Rules to require on-site processing for bulk generators and segregated feedstock delivery to help operators to plan and invest. All plant operators must register on GOBARDHAN portal linked to the national centralised portal and file timely returns, as per the new rules, on waste volumes, processing, and manure quality. ▪ **Strengthen fiscal incentives:** Update SATAT and CFA subsidies for inflation; provide tipping fees from ULBs; enforce offtake mandates for OMCs and gas distributors. ▪ **Integrate into climate goals:** Recognize biomethanation in Renewable Purchase Obligations and emission reduction targets; track performance in SBM and AMRUT dashboards. ▪ **Regulatory Harmonization:** Noting the multi-sectoral nature, objectives, and benefits, mandate convergence between stakeholder ministries to promote and regulate biomethanation economy-wide.Introduce single-window clearance, standard PPP contracts, and real-time transparency in plant operations. ▪ **Uphold technical standards:** Adopt international best practices adapted to Indian waste and climate conditions, in the documents like the standard environmental norms for CBG plants to be made by CPCB.	▪ **Capacity Building:** National agencies (MoHUA, MNRE, BARC) to train operators, engineers, and community volunteers. ▪ **Regulatory Support for Standardization:** Developing and disseminating standardized operating procedures (SoPs) covering appropriate feedstock, common failure modes, and corrective protocols to all plant operators nationwide is a low-cost, high-impact intervention that MoHUA and CPCB are positioned to mandate. ▪ **Financing Tools:** Viability gap funding, annuity-based PPPs, carbon credits, green bonds, and priority sector lending. Support from parallel ministries with aligned goals like MoPNG's incentives, initiatives, and buyout agreements. ▪ **Community Engagement:** Awareness campaigns, demonstration projects, compost buy-back schemes to build trust and participation. ▪ **Showcase Co-Benefits:** Highlight successful models where clean fuel supports buses and digestate is reused in city parks or agriculture, shifting public and political perception. ▪ **GOBARDHAN Digital Infrastructure:** Leverage GOBARDHAN portal as the backbone for plant registration, quarterly/annual reporting, inventory tracking, and performance benchmarking, enabling data-driven policy and accountability across all biomethanation facilities. ▪ **Near-market biomethanation infrastructure:** ULBs to promote decentralised biomethanation plants at or near vegetable, fruit, flower, meat, poultry, and fish markets per SWM Rules 2026. Local bodies to maintain an inventory of all registered plants and upload annually to the centralised portal.

Dry waste management – Recyclable waste

4.4.7. Material Recovery Facilities (MRFs)

Introduction

Material Recovery Facilities (MRFs) are central to India's dry waste management strategy, providing the infrastructure to sort, recover, and recycle plastics, metals, paper, and other dry fractions. The SWM Rules 2026 substantially strengthen the role of Material Recovery Facilities (MRFs). The Rules designate MRFs as EPR uptake points for plastics, e-waste, and Special Care Waste, introduce mandatory quarterly reporting through centralised portals, and require the establishment of MRFs across all cities, positioning them as a key component of the circular economy framework.

Table 46: Material recovery facilities: challenges and solutions

Challenge	Solution
Poor segregation at source leads to contaminated inputs, reducing recyclability and increasing processing costs.	SWM Rules 2026 four-stream segregation mandate + Environmental Compensation for non-compliance will directly addresses this if implemented efficiently. Focus will now be on operationalisation: ULB-level enforcement and collection system redesign to preserve segregation through to MRF intake.
Mixed/contaminated feedstock arriving at MRFs makes financial model precarious — EPR-linked payments pass through multiple intermediary layers and arrive inadequate and unpredictable. Revenue depends almost entirely on volatile recyclable sales.	Raise MRF CapEx subsidy to minimum 75% for small/medium operators (current 35% is insufficient). Public financing of MRF capital with private/ NGO operational management against a defined service fee is the most viable structural model. Establish price stabilisation fund for low-value recyclables seeded from Environmental Compensation penalties.
Outdated/manual processes and limited capital for modernization reduce efficiency and worker safety.	Upgrade with conveyor belts, balers, shredders, and safety measures; leverage PPP models or EPR funding to finance modernization. Implementation of fully automated MRF's.
Irregular inflows, quality control gaps, and downtime create operational bottlenecks.	Establish ward-level decentralized MRFs to spread inflow risk; deploy IoT monitoring for predictive maintenance; enforce clear collection fleet schedules.
Financial instability due to volatile scrap markets and weak access to EPR funds.	Strengthen market linkages by integrating recyclers, aggregators, and dealers; introduce minimum price guarantees; facilitate MRF registration under EPR.

Table 47: Material recovery facilities: policy tweaks and enablers

Policy Tweaks	Enablers
▪ The SWM Rules 2026 already mandate the establishment of MRFs across cities and promote a zero-waste-to-landfill approach. To accelerate implementation, MRF establishment and operationalisation milestones could be linked to SBM-U 2.0 funding and grant disbursement mechanisms. ▪ **Integrate informal workers:** Mandate inclusion of waste pickers in MRFs through through various integration models. (SWM Rules, 2026). ▪ **Tie performance to funding {Regulation Enabled RBF}:** Link central/state grants to outcome indicators such as % of dry waste processed, quantity of recyclables sold, and MRF uptime.	▪ Integrate MRF performance data (waste received, sorted, channelised directly into centralised portal. Create public-facing state dashboards to drive competitive accountability among ULBs.• Innovative Finance: EPR credits, CSR funds, and climate-linked finance mechanisms to stabilize operations. ▪ **Capacity Building:** Training for municipal officials, MRF managers, and waste workers. ▪ **Partnerships:** Leverage expertise of NGOs and private players for efficient management of the MRF's.

4.4.8. Recyclable Waste Management

Recyclable waste (plastics, metals, glass, paper, and textiles) represents a major opportunity within the dry waste stream to drive circularity and reduce landfill dependence. Despite a growing recycling industry in India, fragmentation, lack of quality control, and informal sector exclusion limit recovery potential. Strengthening Extended Producer Responsibility (EPR), enabling standardized collection, and improving traceability are key to scaling circular systems.

Table 48: Recyclable waste management: challenges and solutions

Challenge	Solution
Lack of traceability and inconsistent collection lead to leakages from the recycling chain.	Implement **digital traceability platforms** linking collection centers, MRFs, and recyclers under EPR. Integrate barcoding and GPS tagging for high-value materials.
Informal sector dominates but remains unregulated, lacking safety and fair compensation.	**Formalize informal waste pickers** through registration, training, and inclusion in ULB contracts and EPR buy-back centers.
Low quality and contamination of recyclables reduce end-use market value.	Promote **standardized color-coded bins** and **segregation campaigns;** enforce **producer design standards** for recyclability and minimal packaging contamination.
Volatile scrap prices and weak aggregation affect financial stability.	Create **urban recycling hubs and exchange platforms** for transparent price discovery; provide **EPR-linked minimum price guarantees.**

Table 49: Recyclable waste management: policy tweaks and enablers

Policy Tweaks	Enablers
▪ **Strengthen EPR Enforcement:** Rigorously enforce and expand EPR regulations for plastics, paper, and metal packaging under the Plastic Waste Management (PWM) and Solid Waste Management (SWM) Rules, moving beyond mere credit trading to accountable material recovery. ▪ **Link Funding to Performance:** Mandate ULB-level recycling rate targets and link the achievement of these targets to performance-based funding under schemes like SBM-U 2.0. ▪ **Create Demand for Recycled Content:** Introduce mandatory recycled content standards for key sectors such as packaging, textiles, and construction materials, driving consistent market demand. ▪ **Incentivize Circular Design:** Develop and implement "Right to Repair" frameworks and tax incentives for products designed for durability, repairability, and recyclability.	▪ **Digital Infrastructure:** Develop a national digital marketplace for recyclables (similar to "Recyclers Connect") to connect buyers and sellers seamlessly. ▪ **Green Finance:** Mobilize capital through green bonds, Corporate Social Responsibility (CSR) funds, and EPR credits specifically earmarked for circular economy projects and infrastructure. ▪ **Capacity Building:** Implement large-scale training programs for recyclers, MRF managers, and ULB staff on modern recycling technologies, safety protocols, and business management. ▪ **Market Creation:** Link certified recyclers to public procurement policies and promote consumer-facing eco-label programs to build brand value and market preference for recycled products.

4.4.9.Non-Recyclable Waste Management

Non-recyclable dry waste includes multi-layered plastics (MLP), laminates, contaminated packaging, and low-grade composites that cannot be processed conventionally. These fractions contribute significantly to landfill volume and pose a major environmental hazard if unmanaged.

Table 50: Recyclable waste management: policy tweaks and enablers

Challenge	Solution
High volume of MLPs and mixed plastics lacking recycling value.	SWM Rules 2026 Rule 13 mandates that non-recyclable waste with calorific value ≥1,500 Kcal/kg cannot go to landfill — must go to RDF/WtE. Rule 11 introduces graduated fuel substitution schedule (6%→10%→15%) creating binding downstream demand. However, geographic feasibility varies sharply — West Bengal case (cement plant 600 km from Kolkata) illustrates that mandates without logistics mapping create compliance-on-paper only.
Inadequate infrastructure for waste-to-energy or co-processing.	Approval of new waste-to-energy projects should be contingent on the availability of adequate segregation, recycling, and organic waste processing infrastructure, along with minimum recycling and RDF quality standards. This will help ensure alignment with the circular economy and zero-waste-to-landfill objectives of the SWM Rules 2026.

Table 51: Non-recyclable waste management: policy tweaks and enablers

Policy Tweaks	Enablers
▪ **Expand EPR Scope:** Explicitly include MLP and other non-recyclable packaging waste under the EPR framework, obligating brand owners to manage and fund their end-of-life processing. ▪ **Incentivize Valorization:** Formalize "Thermal Valorization" as a recognized waste management pathway under CPCB guidelines, ensuring it is distinguished from incineration and supported by clear emission standards and operational protocols.	▪ **Technology:** Deploy RDF pelletization units, shredders, and optical sorters to efficiently segregate and prepare mixed plastics for co-processing. ▪ **Finance:** Utilize Viability Gap Funding (VGF) for setting up RDF hubs and tap into climate finance streams for projects that demonstrably reduce GHG emissions through fossil fuel substitution. ▪ **Institutional Frameworks:** Facilitate long-term Memoranda of Understanding (MoUs) between ULBs and cement industries to guarantee a consistent supply of feedstock and offtake of RDF. ▪ **Data and Transparency:** Integrate co-processing data (tonnage, CO_2 saved) into national dashboards like SBM-U to enable real-time monitoring, reporting, and verification of progress.

4.4.10. Hazardous Waste Management

Industrial hazardous waste remains governed by HWM Rules 2016. SWM Rules 2026 introduces a new domestic 'Special Care Waste' stream (4th segregation category) covering pesticide containers, CFL bulbs, expired medicines, batteries. MRFs are designated as deposition centres for this stream. Incinerator ash exceeding toxic metal limits I must be routed to TSDF — a new compliance obligation for WtE operators.

Table 52: Hazardous waste management: challenges and solutions

Challenge	Solution
Lack of collection infrastructure and public awareness for Special Care Waste: The SWM Rules 2026 introduce a dedicated Special Care Waste stream, but most cities currently lack separate collection systems, designated drop-off points, and public awareness on safe disposal practices.	Develop standardised multilingual awareness and communication materials on Special Care Waste management within six months of notification of the Rules. ULBs should establish dedicated collection points, with MRFs designated as authorised drop-off centres.
Inadequate treatment capacity and weak segregation of hazardous waste streams: Limited TSDF capacity and high treatment costs continue to constrain safe hazardous waste management. In addition, municipal facilities often lack the capacity to identify and appropriately route hazardous residues and contaminated waste streams.	Promote regional hazardous waste management clusters with shared treatment infrastructure and explore dedicated financing mechanisms, such as a Hazardous Waste Treatment Fund. Strengthen training and capacity building for facility operators to ensure hazardous waste is correctly identified and routed to authorised TSDFs.
Regulatory uncertainty and limited market development for gasification and pyrolysis technologies: Weak oversight of small-scale facilities, concerns regarding emissions, and the absence of established end-use markets for pyrolysis products continue to limit deployment.	Strengthen registration, certification, and emissions monitoring requirements for gasification and pyrolysis facilities. Develop quality standards and end-use specifications for pyrolysis products while aligning them with RDF quality standards and co-processing requirements.
Weak compliance mechanisms for management of WtE and incineration residues: While the Rules require hazardous ash to be disposed of at authorised TSDFs, many facilities lack formal disposal arrangements and monitoring systems to ensure compliance.	Strengthen enforcement of continuous emissions monitoring requirements and mandate formal TSDF linkages for ash disposal. Incorporate TSDF disposal obligations as a standard requirement in model concession agreements and facility approvals.

Table 53: Hazardous waste management: policy tweaks and enablers

Policy Tweak	Enablers
Establish a dedicated collection and management system for Special Care Waste through existing municipal waste infrastructure.	Develop ward-level collection schedules, map existing MRF infrastructure, and strengthen public awareness on safe disposal practices. CPCB should update MRF operational guidelines to include storage, handling, safety, and channelisation protocols, while linking collection systems with existing EPR frameworks for batteries, lamps, and other regulated waste streams.
Strengthen the regulatory framework for gasification and pyrolysis technologies.	Develop BIS standards and performance benchmarks for gasification and pyrolysis facilities. Mandate third-party verification, emissions monitoring, and compliance under the Hazardous and Other Wastes Rules, 2016.
Harmonise regulatory requirements governing thermal treatment and co-processing pathways.	Align gasification and pyrolysis outputs with RDF quality standards and co-processing requirements under the SWM Rules 2026. Establish a coordination mechanism between MOHUA and MoEFCC to streamline approvals and oversight for waste streams that fall under both regulatory frameworks.
Create an enabling ecosystem for the scale-up of pyrolysis and gasification technologies.	Support pilot and demonstration projects to validate technical and commercial viability. Improve market transparency through disclosure of pyrolysis product quality data on national waste management platforms and facilitate market linkages between technology providers and industrial off-takers.

4.4.11. Sanitary Landfills

Introduction

Sanitary landfills represent the final "end-of-pipe" solution within an integrated MSW management chain, meant to receive only residual, non-recyclable, non-compostable, and inert fractions after upstream segregation, biomethanation, MRF processing, and biomining. SWM Rules 2026 Rule 14 significantly strengthens landfill governance: it prohibits wet waste and C&D waste from entering sanitary landfills, introduces a Sanitary Landfill User Fee set above processing cost to make landfilling economically inferior to recycling, mandates quarterly portal reporting and third-party environmental audits, and requires landfill gas control and collection systems (Schedule II). These are transformative provisions — but their impact depends entirely on enforcement and operationalisation, which remain the principal gap.

Table 54: Sanitary landfills: challenges and solutions

Challenge	Solution
Despite SBM-U 2.0 and AMRUT funding, per-cell costs remain prohibitive for smaller ULBs; land acquisition near urban areas faces NIMBY resistance, regulatory delays, and inadequate state facilitation.	Mobilize blended finance (EPR, CSR, climate-linked funds) to reduce ULB budget dependence; adopt smaller modular cells on reclaimed sites or peri-urban fringes; state governments to support land allocation. State governments to proactively notify and allocate land for regional/ cluster landfills under the Rule 14(1) mandate. Leverage environmental compensation penalty revenues to seed a Landfill Development Fund. Prioritise modular cell construction with phased costs; tie central grant disbursement to land identification milestones.
SWM Rules 2026 (Schedule II, Section F) now mandate installation of landfill gas control and collection systems, and prohibit passive methane escape. However, the internal contradiction between this gas mandate and four-stream segregation (which should result in only inert waste reaching landfills, producing negligible gas) requires regulatory clarification.	Implement the Rule Schedule II gas system mandate for all new landfills immediately. For legacy dumps receiving mixed waste, prioritise LFG-to-Bio-CNG conversion where organic fraction is sufficient (model: Hyderabad Jawahar Nagar). Clarify through CPCB guidance that gas recovery provisions apply primarily to legacy capped dumps and transitional landfills receiving mixed/unsegregated waste, not new landfills receiving only inert residuals.
Methane emission estimates from the same landfill site vary by up to 60-fold depending on methodology (satellite remote sensing vs. IPCC first-order decay vs. direct flux chamber measurement). IPCC models are calibrated for US/European waste compositions and are not valid for Indian conditions.	India-specific methane emission factors, calibrated to domestic waste compositions, moisture content, and temperature profiles, must be developed by CPCB and replace IPCC default models for compliance reporting under SWM Rules 2026. TCLP testing of bio-mining output fractions should be replaced with WELT-equivalent protocols, with a mandatory transition timeline built into the 2026 framework within 24 months.
Public mistrust due to past dumpsites causing odour, health risks, and land devaluation.	Build trust via transparent EIAs, participatory planning, odour-control systems, and community benefit schemes (jobs, local infrastructure); proactive communication to distinguish sanitary landfills from legacy dumps.

Table 55: Sanitary landfills: policy tweaks and enablers

Policy Tweaks	Enablers
▪ Mandate scientific disposal of residual waste only; enforce Rule 15(zi) using GPS tracking, third-party audits, and penalties. ▪ Make LFG capture compulsory for landfills >50 TPD, tied to national methane reduction targets and Article 6 eligibility. ▪ Standardize landfill designs and approvals; SPCBs to issue pre-approved templates and single-window clearances. ▪ Improve financial viability via SBM-U 2.0/AMRUT assistance, PPP annuity models, tipping fees, and carbon finance. ▪ Embed landfill performance in dashboards (gas capture, leachate treatment, area recovery, compliance) to trigger corrective action and link to funding.	▪ Blended finance models drawing from CSR, EPR, climate-linked funds, and carbon credits to offset high capex. ▪ Digital monitoring systems (SCADA, IoT, GPS) for compliance, safety, and performance audits ▪ Community engagement through transparent siting, green buffers, and benefit-sharing schemes. ▪ Institutional strengthening with landfill managers, structured O&M contracts, and real-time reporting. ▪ National alignment by linking landfill standards to SBM-U 2.0 reforms, MoEFCC circulars, and CPCB oversight.

4.5 Scenario Analyses

To assess the emission reduction potential and co-benefits from improved solid waste management practices, three alternative scenarios (ALT 1–3) have been developed. These scenarios build upon existing national missions and policy commitments, including the **Lakshya Zero Dumpsite Mission**, **SBM 2.0**, and **Solid Waste Management Rules, 2026**. The scenarios are summarized below and will be supported by spatial and quantitative analysis through accompanying maps and graphs.

Table 56: Definition of alternative scenarios modelled for methane mitigation

Scenario	Description	Core Actions	Expected Outcome
ALT 1: Legacy Waste + LFG Capture	Focuses on remediating existing dumpsites in line with the Lakshya Zero Dumpsites Mission, Dumpsite Remediation Accelerator Programme and installing landfill gas (LFG) capture systems at priority sites.	Bioremediation and biomining of legacy waste; installation of gas collection and utilization systems (for CBG or power); capping and restoration of remediated sites.	Significant methane abatement from existing landfills; measurable reduction in sectoral methane emissions by 2030.
ALT 2: 100% Waste Management	Envisions full compliance with SWM Rules, 2026—achieving universal segregation, collection, and scientific processing of municipal waste, including integrated urban composting as a diversion pathway for non-landfilled organic waste.	Citywide segregation, decentralized composting, biomethanation, recycling, and formal integration of informal waste workers.	Elimination of new dumpsites; major reduction in methane emissions; co-benefits for employment generation, air quality, and resource recovery.
ALT 3: Integrated Approach (ALT 1 + ALT 2)	Combines dumpsite remediation and LFG capture (ALT 1) with full-scale waste management and integrated urban composting (ALT 2) to establish a circular, near-zero leakage system.	Comprehensive closure and gas capture from legacy sites; 100% segregation, collection, and processing of fresh waste with accelerated composting diversion; institutional and financial integration across the waste value chain.	Significant **methane reduction by 2030;** near-zero leakage pathway consistent with India's climate commitments and SDG 13 (Climate Action).

4.6 Methodology

Solid Waste Management Emissions (IPCC TIER 1 Approach)

- Methane emissions from solid waste disposal (SWD) are estimated using the IPCC 2006 Guidelines for National GHG Inventories (Volume 5: Waste, Chapter 3) and the 2019 Refinement. The Tier 1 method was selected as it is suitable when detailed country-specific data on disposal practices, and landfill management is limited. The methodology combines population projections, municipal solid waste (MSW) generation rates, state-specific waste composition, state-specific percentage of waste going to landfills, and IPCC default parameters to calculate methane (CH_4) emissions. The primary objective is to establish a baseline trajectory of emissions from the year 2019-2047 and evaluate the potential mitigation impact of alternative waste management strategies through scenario analysis. The analysis covers both landfill emissions and methane arising from urban composting activities, and evaluates four scenarios as follows: Baseline: Continuation of current practices, with the proportion of MSW landfilled taken from CPCB (2017–2023) and assumed to decline linearly to 15% by 2040, reflecting an ambitious, policy-driven trajectory consistent with UNEP's circular economy pathways. For urban composting, the organic fraction of non-landfilled waste, calculated by applying the state-specific organic ratio in waste composition to the quantity of waste not sent to disposal sites, represents the biodegradable material available for biological treatment. The composting share and recycling share together account for all non-landfilled waste, ensuring mass balance is maintained across landfill disposal, composting, and recycling pathways throughout the projection period. **ALT 1 (Legacy Dumpsite Remediation and Landfill Gas Capture)**: In this scenario, the focus is on cleaning up old dumpsites (legacy waste) and gradually improving landfill gas (LFG) management to reduce methane emissions over time. From 2026, a certain percentage of old dumpsites is cleaned up (remediated). In 2026–2027, 50% of legacy waste is remediated. In 2028–2029, 25% more is remediated. From 2030 onwards, 100% of the legacy waste is assumed to be remediated. This means that by 2030, only fresh waste contributes to methane emissions. From 2026 onwards, LFG systems begin capturing some of the methane generated. 10% of methane is captured in 2026, 15% in 2028–2029, and 20% from 2030 onwards. As remediation progresses, the amount of waste remaining in old dumps decreases, reducing methane generation from legacy sites. At the same time, the increasing landfill gas capture reduces the share of methane released to the atmosphere.

- Bio-mining and bio-remediation of legacy dumpsites typically generate a **residual reject fraction**, consisting of materials such as contaminated plastics, multilayer packaging, textiles, and inert fines that cannot be recovered or composted. Studies of dumpsite remediation projects in India indicate that this **reject fraction may range from approximately 10–30% of the excavated waste volume**, depending on waste composition and site conditions.
- In many remediation projects, a portion of this material may be utilized as **refuse-derived fuel (RDF)** in industrial facilities such as cement kilns where suitable arrangements exist. However, logistical constraints such as **transport distances, fuel quality requirements, and kiln acceptance limits** may restrict this pathway in some regions.
- For the purposes of this analysis, the reject fraction is assumed to be **ultimately disposed of in controlled landfill facilities or engineered cells following bio-mining operations**, consistent with the remediation guidance provided under the **SWM Rules 2026**. This highlights the importance of parallel investments in **sanitary landfill capacity** to manage residual waste streams generated through large-scale dumpsite remediation.
- **ALT 2 (Progressing towards 100% waste management)**: This scenario models methane emissions from the disposal of fresh municipal solid waste (MSW) at landfill sites. The focus is on how gradual improvements in waste segregation and organic waste diversion reduce the degradable organic carbon (DOC) content of the waste entering solid waste disposal sites (SWDS) over time. From 2026 onwards, DOC values were dynamically reduced to simulate enhanced organic waste diversion, corresponding to 25% organic waste reduction by 2035 and 100% by 2047. Each year's total waste entering SWDS was divided into Organic (biodegradable) waste fraction and inorganic (non-biodegradable) waste. This scenario represents a progressive policy pathway emphasizing source segregation, composting, and organic waste diversion, leading to a gradual reduction in methane emissions even without landfill gas capture or active dumpsite remediation.
- This scenario also incorporates urban composting, with the non-landfilled organic fraction progressively diverted to composting as source segregation improves. The proportion of organic waste directed to composting is increased over time to reflect the gradual expansion of composting infrastructure and treatment capacity. Using the 2022 composting rate as the baseline, the share of organic waste composted is assumed to increase to 1.5 times the baseline level by 2026, 2 times by 2028, 2.5 times by 2030, and 3 times by 2047, representing the increasing diversion of biodegradable waste from disposal sites to composting facilities in line with national waste management objectives.
- National waste statistics as per CPCB 2022-23 indicate that approximately **17% of municipal solid waste (28,576 TPD)** remains unaccounted for within formal municipal collection and processing systems. This fraction likely represents waste that is openly dumped, burned, or managed outside official municipal reporting frameworks.

For the purposes of **Scenario ALT-2**, this currently unaccounted waste is assumed to be progressively integrated into the formal waste management system through improvements in collection coverage and source segregation. In the modelling framework, this additional waste volume is distributed across the same treatment pathways assumed for formally collected waste streams.

- **ALT 3 (Combined Scenario):** Under this integrated scenario, methane emissions decline substantially over time due to the **combined effects** of reduced organic carbon content (lower DOC) in new waste streams, active remediation of legacy dumpsites (removing old methane sources), progressive gas capture at operating sites, and accelerated urban composting of the non-landfilled organic fraction. This reflects a holistic waste sector mitigation pathway, aligning with the long-term national vision for sustainable waste management and climate goals. By 2047, nearly all fresh organic waste is diverted or treated, legacy waste is remediated, and landfill methane capture systems are fully operational, resulting in the lowest modeled emission levels among all scenarios.

Activity Data and data sources:

a. **Population estimates** were taken from the *Population Projections for India and States, 2011–2036, Ministry of Health & Family Welfare.* These projections were used as the official demographic baseline for the period up to 2036. For the period 2037–2047, population values were extrapolated using a linear regression trend function. The year-wise population estimates provided the foundation for calculating total municipal solid waste (MSW) generation.

b. **Per capita Waste Generation**: The per capita waste generation rate was estimated using the classification developed by the Central Pollution Control Board (CPCB, 2000b)[345] and subsequent refinements provided by Annepu (2012)[346]. The rates vary by the size of the urban population, reflecting differences in consumption patterns and waste intensity across settlements.

Table 57: Per capita waste generation rates by urban population size

Population size	Waste generation (kg/capita/day)
> 2,000,000	0.55
1,000,000 – 2,000,000	0.46
500,000 – 1,000,000	0.48
100,000 – 500,000	0.46
< 100,000	–

c. **Total annual waste generated** (MSWT) was then calculated as:

MSWT=Population*Per Capita Waste Generation (kg/person/day)*365

This provided the annual activity data input required for the IPCC Tier 1 methodology.

d. **Quantity of Waste Disposed at a site**: The proportion of total municipal solid waste (MSW) directed to solid waste disposal sites (SWDS) was derived from CPCB annual reports for 2017–2023 for each state. For future years, this proportion was assumed to gradually decline to 15% by 2047. This assumption is a policy-driven, ambitious scenario rather than a projection derived from historical trends. It is also consistent with the direction and ambition of UNEP's Global Waste Management Outlook and zero-waste / circular economy pathways, which call for a progressive minimization of landfilling as part of sustainable waste management.

e. **Degradable Organic Carbon (DOC):** DOC values were estimated dynamically for each state and year, based on state-specific waste composition data combined with IPCC default DOC content values for each waste type. Waste composition (paper, garden, and park waste, food waste, wood, textiles) was obtained from supplementary literature sources.

= (0.40×)+(0.20×)+(0.15×)+ (0.43×)+(0.24×)

where:

=(h)h,

(0.40), (0.20), (0.15), (0.43), (0.24)

The DOC formula was applied across years (2026–2047) to generate a time series of DOC values, dynamically reflecting changes in waste composition. For the **Baseline** and **ALT 1** (legacy waste remediation and gas recovery), a constant DOC value was applied based on literature estimates representative of typical mixed municipal solid waste in Indian landfills. For **ALT 2 (Fresh waste sent to landfill)**, the DOC fraction was **dynamically reduced from 2026 to 2047** to simulate gradual improvement in waste segregation and organic waste diversion. The annual DOC decline reflects a linear reduction in the proportion of organic fractions (paper, food, garden, wood, and textiles). In the **ALT 3 (combined scenario)**, the same time-varying DOC profile from ALT 2 was applied, combined with landfill gas recovery and legacy waste remediation measures from ALT 1.

- **Fraction of DOC dissimilated (DOCf):** The DOCf parameter represents the proportion of DOC that is degraded under anaerobic conditions. Given that Indian landfills typically operate under warmer climatic conditions (average landfill temperature ~35 °C), a higher DOCf value was adopted. Following a 2018[347] study, DOCf was set at **0.77**. This value reflects the greater potential for organic matter degradation at elevated temperatures, leading to enhanced methane generation relative to temperate-region landfills.

IPCC default values were applied for the following parameters:

- **Methane Correction Factor (MCF):** The MCF represents the extent to which degradable organic carbon (DOC) decomposes anaerobically under different landfill conditions. It has been kept at a constant (0.4) throughout the years.
- **Fraction of methane in landfill gas (F):** The F parameter, denoting the fraction of methane in landfill gas, was fixed at the IPCC default value of 0.5.
- **Methane recovery (R):** Methane recovery through LFG systems was included from 2026 onwards in ALT 1 and ALT 2. The capture efficiency increased gradually with system expansion: 10% of methane captured in 2026, 15% in 2028–2029, and 20% from 2030 onwards.
- **Oxidation factor (OX):** The OX factor, accounting for oxidation of methane in cover soils, was set at the IPCC default of 0 for landfills.

Methane (CH_4) emissions from solid waste disposal were estimated using the IPCC Tier 1 equation:

$$CH^4 Emissions = \left(MSWT \times MSWF \times MCF \times DOC \times DOCf \times F \times \frac{16}{12} \right) - R \times (1 - OX),$$

Where:

=

=

=

=

=

Methane (CH_4) emissions from urban composting were estimated using the IPCC Tier 1 equation:

CH_4 EMISSIONS FROM BIOLOGICAL TREATMENT

$$CH_4\ Emissions = \sum_i (M_i \bullet EF_i) \bullet 10^{-3} - R$$

Where:

M_i = mass of organic waste treated by biological treatment type i, Gg

EF = emission factor for treatment i, g CH_4/kg waste treated

i = composting or anaerobic digestion

R = total amount of CH_4 recovered in inventory year, Gg CH_4

Limitations **Choice of IPCC Tier 1 Methodology**

Methane emission estimates in this study are calculated using the **IPCC Tier 1 methodology** for solid waste disposal sites. This approach applies globally recommended default parameters, including methane generation potential (L_0) and decay rate constants (k values), rather than country-specific empirical measurements.

The Tier 1 approach was selected due to the **limited availability of consistent India-specific landfill methane generation data**, particularly long-term measurements of waste decomposition dynamics and methane recovery from dumpsites. While **Tier 2 methods**, which rely on country-specific parameters, can improve accuracy, such datasets remain limited for many Indian cities and legacy dumpsites.

As a result, the emission estimates presented in this report should be interpreted as **indicative estimates of methane mitigation potential rather than precise site-level emission inventories**. Future improvements in national waste data systems and field measurements could enable the adoption of **Tier 2 or Tier 3 methodologies** using locally derived decay rates and waste composition parameters.

Limitations in Historical Landfilling Data

A key challenge in estimating methane emissions from legacy dumpsites in India is the **limited availability of consistent historical records on waste quantities deposited at landfill and dumpsite locations**. Most municipal bodies do not maintain long-term datasets on annual waste disposal volumes, particularly for sites that operated as open dumps prior to the implementation of modern solid waste management rules.

As a result, the baseline estimates of methane emissions from legacy waste used in this analysis are based on **reconstructed waste accumulation estimates derived from available national waste generation statistics and dumpsite inventories**, rather than site-specific historical disposal records. This introduces uncertainty in the absolute magnitude of emissions attributed to legacy waste.

Consequently, the methane mitigation outcomes presented under **Scenario ALT-1 (dumpsite**

remediation) should be interpreted as **indicative estimates of potential emission reductions**, reflecting the order of magnitude of mitigation achievable through legacy waste remediation rather than precise site-level emission projections.

4.7 Scenario Analysis and Outcomes: Methane Emission Trends (2019–2047)

The graph illustrates projected methane emissions from India's solid waste sector under four scenarios — **Business-as-Usual (BAU)**, **ALT 1 (Legacy Waste Remediation + LFG Capture)**, **ALT 2 (100% Waste Management(collection, segregation, transportation, processing, urban composting)**, and **ALT 3 (Integrated Approach)** — spanning the period **2019 to 2047**.

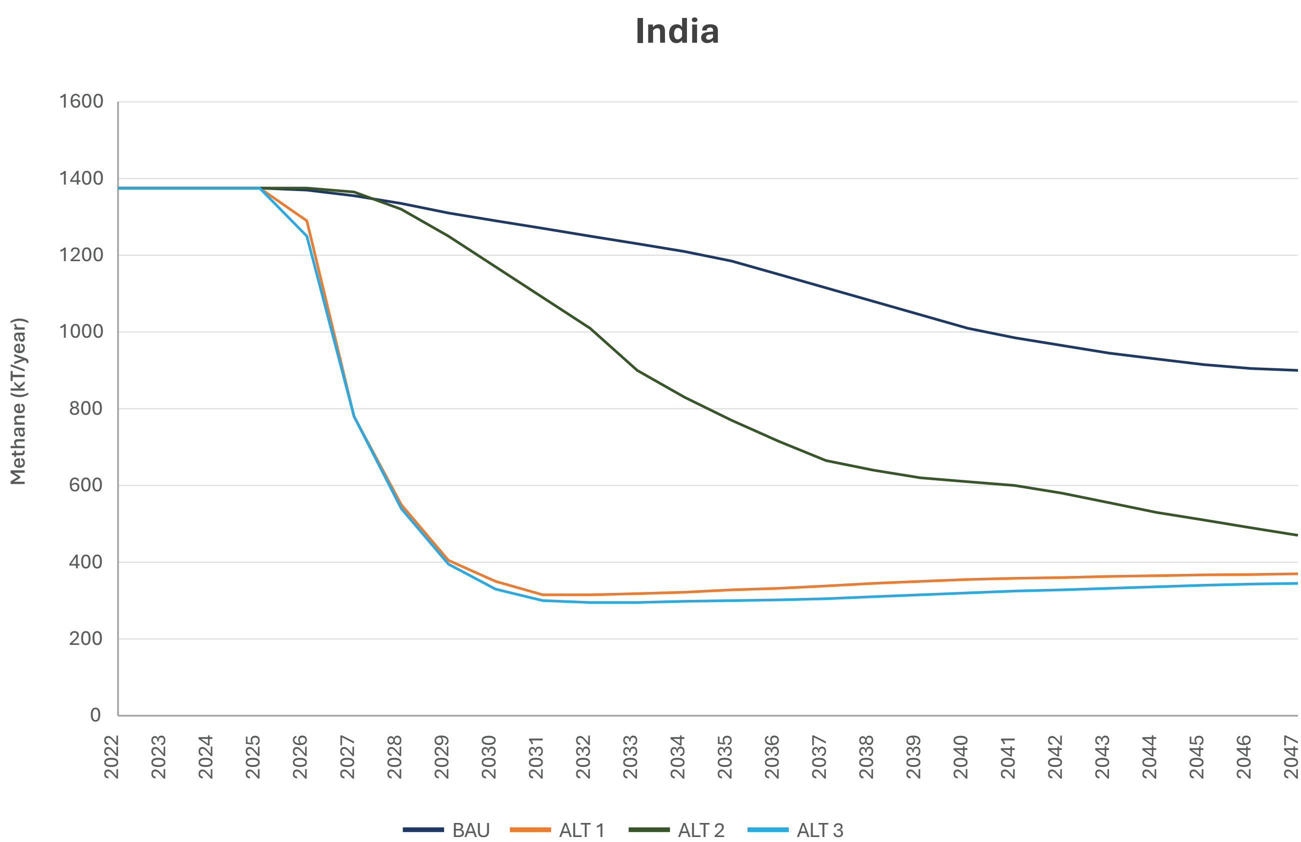


Figure 33: Projected methane emissions from the waste sector under BAU and alternative scenarios, 2019 to 2047

Table 58: Key observations and insights from the scenario analysis

Scenario	Key Observations / Insights	Trend Summary
Business-as-Usual (BAU)	Methane emissions remain relatively stable around **1,200–1,300 kT/year** until **2025,** followed by a slow and gradual decline after **2030**. This indicates limited improvements in waste management practices and continued dependence on open dumping and uncontrolled landfilling. Even by **2047**, emissions remain significant (~600 kT/year), highlighting that current incremental policy actions alone will not yield optimal methane reductions.	**Slow, linear decline** due to partial compliance and weak enforcement of existing waste regulations.
ALT 1: Legacy Waste remediation + LFG Capture	A sharp emission drop occurs between **2025 and 2030,** driven by the impact of pursuing aggressive dumpsite remediation and the simultaneous installation of landfill gas (LFG) capture systems. However, **post-2030, the emissions plateau at low levels,** implying that once legacy waste is addressed, further reductions are dependent on LFG capture systems and limited without other complementary systemic interventions. This suggests ALT 1 alone offers a strong short-term impact but lacks long-term momentum for continued abatement.	**Steep early decline,** stabilizing after 2030 once legacy sites are remediated, followed by lower emissions due to successful gas recovery
ALT 2: 100% Organic waste Management (source segregation and organic waste diversion from landfills)	Emissions decline more gradually but persistently compared to ALT 1, beginning around 2025 and continuing through 2045. The trajectory reflects nationwide successful implementation of segregation, composting, biomethanation, and recycling systems. While this approach takes longer to deliver full benefits, it results in deep and sustained methane mitigation and supports broader co-benefits like air quality improvement and employment.	**Steady, long-term decline** achieving near-zero emissions by 2047 through systemic waste management transformation.
ALT 3: Integrated Approach (ALT 1 + ALT 2)	The integrated pathway achieves the **most rapid and sustained decline,** with methane emissions nearing **zero by 2030** and remaining minimal thereafter. This scenario combines immediate gains from dumpsite remediation and gas capture (ALT 1) with enduring benefits from universal waste management systems (ALT 2). It represents a circular and near-zero leakage waste management model consistent with India's climate and sustainability goals.	**Fastest and deepest cut,** aligning with SDG 13 and India's SLCP mitigation targets.

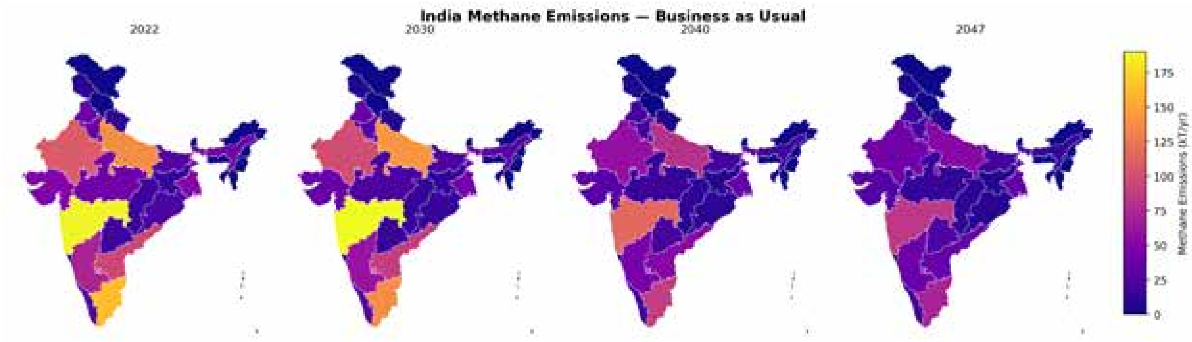
Inference

- ALT 3 represents the most effective and balanced strategy, capable of achieving significant methane reductions by 2030 and aligning with India's SLCP and SDG 13 (Climate Action) targets.
- ALT 1 delivers a rapid short-term win, but its impact plateaus after 2030, emphasizing the need to couple legacy waste remediation with broader systemic interventions.
- ALT 2 offers a slower yet enduring pathway, strengthening institutional and community systems for long-term emissions control and co-benefits such as improved air quality and job creation.
- Collectively, the scenarios highlight that integrated policy action—linking dumpsite remediation, LFG capture, and 100% scientific waste management—is essential to achieve deep decarbonization and sustained methane mitigation in India's waste sector.

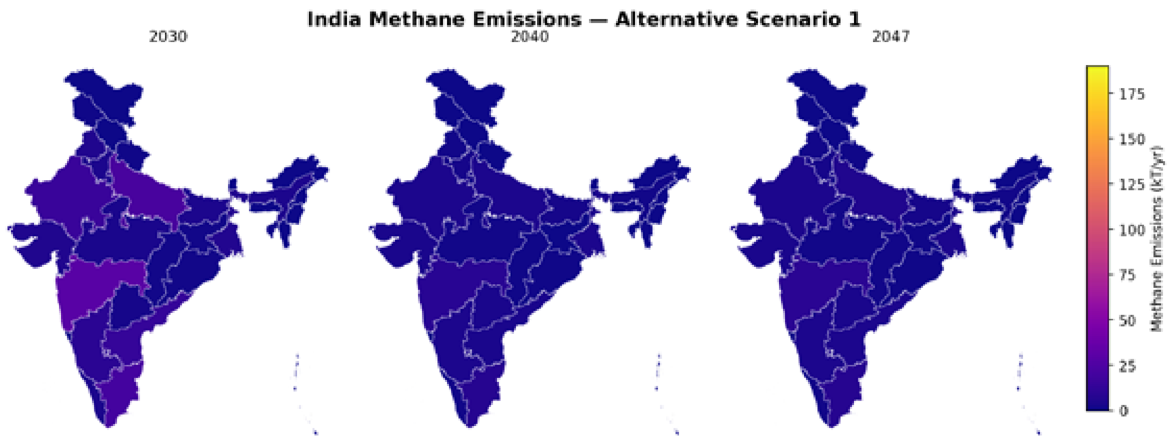
4.8 Spatial Analysis of Methane Emissions across Scenarios (India, 2030–2047)

The four panels present spatial projections of **methane emissions from the waste sector** across Indian states under different scenarios: **Business-as-Usual (BAU), Alternative Scenario 1 (ALT 1: Legacy Waste + LFG Capture), Alternative Scenario 2 (ALT 2: 100% Waste Management),** and **Alternative Scenario 3 (ALT 3: Integrated Approach).** Each map shows emission intensity changes from **2030 to 2047,** with darker shades indicating **lower methane emissions** and lighter (yellow/orange) shades representing **higher emissions.**

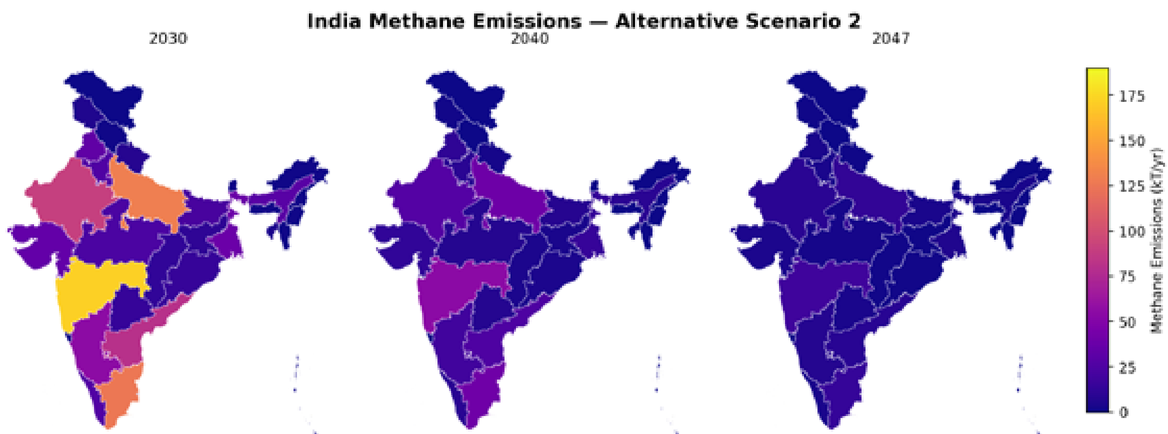
BAU trends for 2020,2030,2040,2047



ALT 1 trends for 2030,2040,2047



ALT 2 trends for 2030,2040,2047 (assuming no dumpsite remediation)



ALT 3 trends for 2030,2040,2047

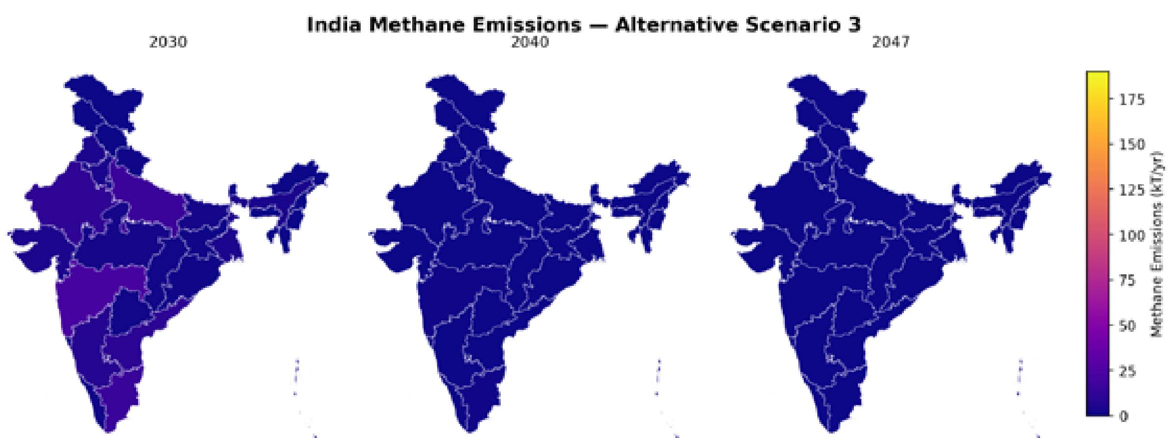


Figure 34: Spatial distribution of methane emissions across India under BAU and alternative scenarios, 2022 to 2047

Table 59: Spatial and scenario correlation of methane emission pathways, 2030 to 2047

Scenario	Observation (from Spatial Maps)	Inference (Linked to Scenario Design)
1. Business-as-Usual (BAU)	▪ High methane intensities (yellow/ orange) in 2030, especially in **Maharashtra, Rajasthan Uttar Pradesh, Tamil Nadu, and Andhra Pradesh,** where urban waste generation is highest. ▪ Gradual decline by 2047, yet medium to high emissions persist across several states.	▪ Reflects **limited improvement** in waste management infrastructure and **continued reliance on open dumping and unmanaged landfills.** ▪ Methane emissions remain high due to absence of large-scale remediation or segregation interventions. ▪ Aligns with **BAU scenario design,** where waste management continues at current efficiency levels — insufficient for meeting **India's SLCP or SDG 13 targets.**
2. Alternative Scenario 1 (ALT 1: Legacy Waste + LFG Capture)	▪ Rapid drop from medium to low methane levels (deep purple) between **2030–2040,** visible across high-emission states such as Maharashtra, Rajasthan, Andhra Pradesh, Uttar Pradesh and Delhi NCR. ▪ By 2047, emissions are largely contained.	▪ Mirrors **ALT 1 design focus on legacy waste remediation and landfill gas capture.** ▪ Demonstrates **quick and significant methane reduction** due to dumpsite biomining, capping, and gas recovery. ▪ However, without **fresh waste diversion and 100% processing,** residual methane from ongoing waste generation may continue beyond 2040, matching the **short-term but localized effectiveness expected** under ALT 1.
3. Alternate scenario 2: 100% Organic waste Management (source segregation and organic waste diversion from landfills)	▪ Moderate emissions persist in 2030, with higher levels in southern and western India states (Maharashtra, Uttar Pradesh, Tamil Nadu, Rajasthan, Andhra Pradesh) ▪ By 2040, sharp decline and **near-zero emissions by 2047** across all states.	▪ Matches **ALT 2 pathway** emphasizing **universal segregation, decentralized composting, and scientific processing.** ▪ Depicts a **gradual, system-wide emission decline** as infrastructure scales up nationwide. ▪ Confirms the scenario's **long-term systemic transformation,** delivering strong co-benefits for **jobs, recycling, and air quality**—consistent with its **100% compliance and sustainability goals.**
4. Alternative Scenario 3 (ALT 3: Integrated Approach — ALT 1 + ALT 2)	▪ Methane emissions drop drastically by **2030,** with nearly uniform deep purple across India. ▪ Minimal change thereafter, indicating **sustained control and stability.**	▪ Perfectly aligns with **ALT 3's integrated framework,** combining **legacy dumpsite remediation (ALT 1) and 100% waste management (ALT 2).** ▪ Delivers **immediate and enduring methane reductions**—up to **50% by 2030,** sustaining low emissions through 2047. ▪ Represents the **optimal circular economy pathway,** ensuring a **near-zero leakage system** consistent with **India's NDC and SLCP commitments.**

Conclusion: Scenario-Based Methane Mitigation Pathways

The comparative spatial and scenario analysis clearly demonstrates that **progressive policy and infrastructure** interventions yield substantial methane reductions in India's waste sector.

Under the **Business-as-Usual (BAU)** pathway, emissions remain persistently high, underscoring the inadequacy of incremental improvements. In contrast, **ALT 1 (Improved Legacy Waste Management+ LFG Capture)** delivers rapid, short-term abatement through dumpsite remediation and landfill gas recovery but offers limited long-term sustainability without concurrent fresh waste management reforms. **ALT 2 (100% Waste Management)** shows a steady, system-wide decline, reflecting the power of full compliance with waste segregation and processing mandates to drive enduring emission control and socio-economic co-benefits.

The **Integrated Approach (ALT 3)** emerges as the most effective and resilient pathway. By combining immediate gains from legacy waste interventions with the sustained benefits of comprehensive waste management, it achieves significant **methane reductions by 2030** and maintains near-zero emissions through 2047. This integrated model exemplifies a **circular economy transition,** aligning with India's **Short-Lived Climate Pollutant (SLCP) mitigation goals, Nationally Determined Contributions (NDCs), and SDG 13 (Climate Action).**

In essence, the analysis reinforces that **integrated, multi-layered strategies**—rather than isolated interventions—are key to transforming the waste sector from a major methane source into a cornerstone of India's low-emission, resource-efficient future.

4.9 Summary for policy makers: Key findings

This report outlines key recommendations to improve landfill management and reduce methane emissions. We first examine the structural functions of landfills to understand how methane is produced. By exploring the concept of landfills and the methane emissions they generate, the report comprehensively compares the various levers within the waste management ecosystem that determine our necessary actions.

Two roadmaps act as guiding instruments for stakeholders to effectively manage waste. The first roadmap tackles existing dumpsites by focusing on bioremediating existing landfills, sending waste to proper processing and capturing methane being generated and converting methane into useful energy. The second roadmap aims to ensure minimal waste reaches dumpsites in the future through complete waste management, thereby avoiding methane generation in landfills/dumpsites altogether. The central finding of this report is that methane, whether generated at existing landfills or avoided through prevention, has the capability to be translated into significant energy potential.

Table 60:: Summary for policy makers: key findings and recommendations by chapter

Chapter	Key Finding	Recommendations
INTRODUCTORY ANALYSIS	The type of waste has evolved from mostly organic to a more complex mix.	Policies must adapt to the changing composition of waste.
	A large percentage of waste going to landfills is still organic.	Better source segregation can reduce the percentage of organic waste reaching landfills.
	It's important to understand the pros and cons of decentralized vs. centralized approaches.	Choose the most viable approach based on geography and funds.
	There are growing emissions and significant data gaps, especially in rural areas.	Collect better data and conduct on-the-ground validation.
	There are infrastructure and capacity constraints, particularly for recycling and processing.	Increase investment in waste reduction, recycling, and composting infrastructure.
	The informal sector plays a crucial but unformalized role.	Further formalization and recognition of the role of waste pickers ("kabbadiwaalas") is needed.
	While administrative hierarchy exists, funds for ULBs and panchayats are not efficiently managed.	Ensure transparency in the funding system.
LANDFILL AND METHANE EMISSIONS	There is a fundamental difference between unscientific dumpsites and sanitary landfills.	Acknowledge the difference and prioritize converting dumpsites into scientific landfills.
	Global estimation tools for methane are often inefficient for India's context.	Use localized tools for methane assessment.
	Dumpsites are a major and growing source of methane emissions due to high organic content.	Supervision of the mandate for methane capture and utilization systems at old dumpsites must be done to check for failed implementation
	There is still untapped potential for renewable energy from landfill gas in various locations in India	Accelerate biomining and landfill reclamation to recover resources and energy.

Chapter	Key Finding	Recommendations
ECOSYSTEM OF LANDFILL MANAGEMENT	A comparison of financial tools shows that traditional funding is inadequate.	Use innovative financial tools like the upcoming India Carbon Market and CSR funds to finance projects.
	A comparison of technologies shows that Waste-to-Energy (WTE) plants have failed in India.	Promote appropriate technologies for the Indian context, such as biomining and decentralized composting.
	The "L1" public procurement method (lowest bidder) hinders the adoption of innovative technologies.	Revise procurement policies to incentivize sustainable and innovative solutions.
	There are significant gaps in policy enforcement, despite strong regulations.	Strengthen enforcement of existing rules and use incentives to promote compliance.
	The informal sector needs to be integrated formally.	Integrate waste pickers and recyclers into the formal system.
ROADMAPS AND SCENARIO ANALYSIS	Roadmap 1: Ensuring the closure of existing dumpsites	Goal- Aims to achieve the goal of utilising methane that would otherwise enter the atmosphere and cause climatic impact, through development of ALT 1
	ALT 1 Finding: Following policy targets in India, ALT 1 focuses on closing existing dumpsites through bioremediation and capturing emitted methane and further utilising it.	**Key Recommendations:** Prioritize **remediation of large dumpsites** under SBM 2.0, *Lakshya Zero Dumpsite and DRAP.*. Install **landfill gas (LFG) capture and utilization systems** till 2047 (for CBG or power generation) at high-emission sites. Ensure **post-remediation** monitoring and long-term maintenance of capped sites. **Key Takeaways:** Offers **quick methane reduction gains** from legacy waste. Effective short-term measures **require integration with ongoing waste management** for lasting impact.
	Roadmap 2: Ensuring better diversion to reduce the need for creation of new dumpsites	Goal- Aims to achieve the goal of avoiding potential methane generation through better waste management, through development of ALT 2
	ALT 2 Finding: Following policy targets in India, ALT 2 focuses on successful waste management.	**Key Recommendations:** Achieve **universal segregation and collection** at source across all cities. Scale up **decentralized composting, biomethanation, and recycling facilities.** Integrate **informal waste workers** into formal systems for inclusive implementation. **Key Takeaways:** Ensure **long-term systemic emission control** and circular resource recovery. Generates **co-benefits**—improved air quality, reduced landfill load, and employment opportunities.

Chapter	Key Finding	Recommendations
	Combining the policy targets of ALT 1 and ALT 2, ALT 3 emphasises on ensuring simultaneous work on closing existing dumpsites and ensuring no future dumpsites	**Key Recommendations:** Combine **legacy waste remediation with end-to-end fresh waste management.** Develop **state-level methane mitigation roadmaps** linking LFG capture, composting, and biomethanation. Establish **monitoring, reporting, and verification (MRV)** systems to track methane reductions. **Key Takeaways:** Delivers **fastest and deepest methane reduction—up to 50% by 2030.** Represents an **optimal circular economy pathway,** aligning with **India's NDC and SLCP targets for 2030 and beyond.**

Annexure

Link to WM cycle

Table 61: Municipal solid waste management plan for municipal councils and A, B and C class cities

Approximate Population	ULB Generating Tonnes/Day	Primary Doorstep Segregated Collection Equipment and Vehicles	Secondary Collection of Street Waste Equipment and Vehicles	Decentralised or Centralised Processing, Recovering and Recycling	Waste Disposal at Common/ Regional Landfill
Up to 50,000	2.0–2.5 TPD per 10,000 population	- Door-to-door collection services through containerised handcarts or tricycles - 2 bins for storage of wet waste and dry waste - 10–15 l capacity domestic bins, one with lid (as per CIPET specifications) - 2 community bins of 60 l capacity (20–30 kg) or 120 l capacity (40–60 kg) or 240 l capacity (80–120 kg) or 1.1 m³ capacity (300–450 kg) - Bulk generators at source require 120 l (49 kg), 240 l (96 kg) bins - Contract with private firm, RWA, and NGO, if possible	- 3–4 m³ containers to be placed at the rate of 4 per km² area or 1 per 5,000 population - Transportation of containers by tractor having container lifting device	- Decentralised processing through composting or biogas technology for both biodegradable and recyclable waste collected from households, shops, etc. - If no land is available for decentralised processing, town level processing must be done and direct transfer of waste collected from streets and drains to disposal site through tractors at the rate of 1 tractor per 10,000 population	- Inert only to be transported to common or regional landfill facility
50,000 to 100,000	10–30 TPD @ 250 gms/ capita/day	- 80% households to be served by covered tractor or covered LCV for door-to-door collection at 1 vehicle per 1,500 households, shops, etc. - 20% households to be served by tricycles with container for door-to-door collection or handcarts for narrow lanes at 1 tricycle per 200 units - Direct transfer of waste from tricycle to tractor or LCV to processing facility	- 100% street sweeping waste to be collected in containerised handcarts and deposited in 3–4 m³ containers - Containers to be placed at 4 per km² area or 1 per 5,000 population - Containers to be lifted by tractors or twin bin dumper placers	- 50% decentralised processing of waste if suitable space is available - If no space, domestic and trade waste to be processed at centralised facility with resource recovery	- Inert only from the processing facility - Street sweepings and silt from the drains may be landfilled
1,00,000 to 5,00,000	25–150 TPD	- 75% door-to-door collection through covered LCV - 25% door-to-door collection through containerised tricycles or handcarts from narrow lanes - Direct transportation of waste to processing facility if distance is under 5 km, or transportation through compactors if distance is longer - Compactors to be deployed based on capacity of vehicle and volume or weight of waste	- Street sweeping and silt from drains may be collected in containerised handcarts and taken to secondary storage depot having 1.1–4.0 m³ metal containers - Containers to be placed at 4 per km² area or 1 per 5,000 population - Containers to be lifted by twin bin dumper placers or refuse collector or compactor machines - Dumper placers and compactors based on capacity of vehicle and volume or weight of waste	- 100% door-to-door collected waste to be processed at decentralised sites if available, or processed at one facility - Composting, biogas, or RDF facilities may be created	- Inert street sweeping, silt from the drains, and residual waste from processing plants to be landfilled

Approximate Population	ULB Generating Tonnes/Day	Primary Doorstep Segregated Collection Equipment and Vehicles	Secondary Collection of Street Waste Equipment and Vehicles	Decentralised or Centralised Processing, Recovering and Recycling	Waste Disposal at Common/ Regional Landfill
Population between 5–10 lakhs	150–400 TPD	- 75% door-to-door collection through covered LCV - 25% door-to-door collection through containerised tricycles or handcarts from narrow lanes - Direct transportation of waste to processing facility if distance is under 5 km, or transportation through compactors if distance is longer - Compactors to be deployed based on capacity of vehicle and volume or weight of waste	- Street sweeping and silt from drains may be collected in containerised handcarts and taken to secondary storage depot having 1.1–4.0 m^3 metal containers - Containers to be placed at 4 per km^2 area or 1 per 5,000 population - Containers to be lifted by twin bin dumper placers or refuse collector or compactor machines - Dumper placers and compactors to be deployed based on capacity of vehicle and volume or weight of waste	- 100% door-to-door collected waste to be processed at decentralised sites if available, or processed at one facility - Composting, biogas, or RDF facilities may be created	- Inert street sweepings, silt from the drains, and residual waste from processing plants to be landfilled
Above 10 lakhs	400 TPD & above	- 75% door-to-door collection through covered LCV - 25% door-to-door collection through containerised tricycles or handcarts from narrow lanes - Direct transportation of waste to processing facility if distance is under 5 km, or transportation through compactors or transfer stations if distance is longer - Compactors to be deployed based on capacity of vehicle and volume or weight of waste - Large containers of more than 10 t capacity with hook loaders may be deployed at transfer stations for bulk transfer of waste through processing or disposal facility	- Street sweeping and silt from drains may be collected in containerised handcarts and taken to secondary storage depot having 1.1–4.0 m^3 metal containers - Containers to be placed at 4 per km^2 area or 1 per 5,000 population - Containers to be lifted by twin bin dumper placers or refuse collector or compactor machines - Dumper placers and compactors to be deployed based on capacity of vehicle and volume or weight of waste	- 100% door-to-door collected waste to be processed at decentralised sites if available, or processed at one facility - Composting, biogas, or RDF facilities or waste-to-energy power plants may be installed, as power plants will not be viable if the waste is less than 500 TPD	- Inert street sweepings, silt from the drains, and residual waste from processing plants to be landfilled

Timelines for scenarios analysis

Table 62: Timelines and parameter assumptions for the scenario analysis

Year	% Legacy Dumpsites Remediated	% Fresh Waste to old Sites	LFG capture %
2022: Baseline	15%	46%	-
2026	50%	40%	10%
2028	75%	35%	15%
2030	100%	30%	20%
2047	-	0 (Linear Decrease)	0 (Linear Decrease)

Justification for Scenario Assumptions: Landfill Remediation, Fresh Waste Flow, and LFG Capture

1. Legacy Dumpsite Remediation (%)

Table 63: Justification for legacy dumpsite remediation assumptions

Year	% Legacy Dumps Remediated	Justification / Rationale
2022	**15%**	As per CPCB (2022–23), 2,474 dumpsites have been identified, of which 377 (≈15%) have been reclaimed/capped and 44 (≈2%) converted into sanitary landfills. This forms the baseline year for the model.
2026	**50%**	Assumes accelerated remediation achieved between 2022–2026 under SBM-U 2.0, the Lakshya Zero Dumpsite initiative and DRAP, driven by increased funding and large-scale adoption of biomining and bioremediation.
2028	**75%**	Building on the accelerated remediation achieved under SBM-U 2.0 and the Lakshya Zero Dumpsite initiative, progress is assumed to continue under DRAP. However, implementation constraints such as prioritization of only high-impact dumpsites, contract delays, slow processing rates, and post-remediation planning gaps are expected to limit progress to 75% remediation by 2028.
2030	**100%**	Full closure/remediation of legacy dumpsites by 2030 assumes sustained progress in biomining and enforcement of NGT and CPCB directives. This also aligns with the "Garbage Free Cities" vision and India's zero-landfill transition roadmap under SBM-U 2.0.
2047	**—**	All dumpsites are assumed remediated and scientifically closed by this point. Only engineered landfills remain operational for inert and process rejects.

2. Fresh Waste Flow to Old Landfill Sites (%)

Table 64: Justification for fresh waste flow to old landfill sites

Year	% Fresh Waste to Old Sites	Justification / Rationale
2022	**46%**	Derived from CPCB/SPCB data (2022–23): **54% of municipal solid waste is processed or treated,** implying **46% remains untreated** and continues reaching dumpsites. This forms the baseline year.
2026	**40%**	Gradual improvement is expected as new processing and recovery facilities (MRFs, composting, RDF) are scaled up. However, **fresh waste still reaches partially cleared sites,** where cleared portions are temporarily reused for staging or processing. Reflects moderate **improvement,** not overly optimistic.
2028	**35%**	As legacy sites near 75% remediation, the proportion of fresh waste reaching old sites continues to drop due to expanded waste processing infrastructure and ULB compliance pressure under SBM ranking systems.
2030	**30%**	By this stage, most cities are expected to have operational transfer stations and new engineered cells for inert disposal. Continued reduction represents infrastructure stabilization rather than aggressive policy gains.
2047	**0% (Linear Decrease)**	By 2047, it is assumed **no fresh waste** reaches legacy sites. All cities are expected to achieve **complete diversion** to processing and scientific disposal systems as per the long-term **zero-landfill** pathway.

3. Landfill Gas (LFG) Capture and Utilization (%)

Table 65: Justification for landfill gas capture and utilisation assumptions

Year	LFG Capture %	Justification / Rationale
2022	**–**	No baseline data exists for LFG capture in India. Current landfill management largely lacks gas extraction systems. *Policy instruments such as the SWM Rules (2026), CPCB's Legacy Waste Guidelines (2019), and SBM-U 2.0 Toolkit offer frameworks but lack mandatory LFG capture provisions.*
2026	**10%**	Although the SWM Rules, 2026 mandate landfill gas capture systems at sanitary landfills, they do not prescribe a minimum gas capture efficiency or target percentage. Accordingly, a conservative initial uptake rate of 10% has been assumed, reflecting the likely implementation of pilot or partial-scale projects under emerging national methane mitigation initiatives.
2028	**15%**	As more cities undertake biomining and landfill stabilization, the potential for integrating modular flaring and LFG-to-energy systems increases. A 15% capture assumption reflects policy learning and early replication.
2030	**20%**	Anticipates scale-up through dedicated policy and funding mechanisms such as carbon finance, viability gap funding (VGF), etc. Reflects mainstreaming of methane recovery before landfill closure.
2047	**0% (Linear Decrease)**	After full remediation and closure, no new methane generation occurs, hence LFG capture installations cease. Post-closure, emissions are assumed negligible due to stabilization and inert-only disposal.

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