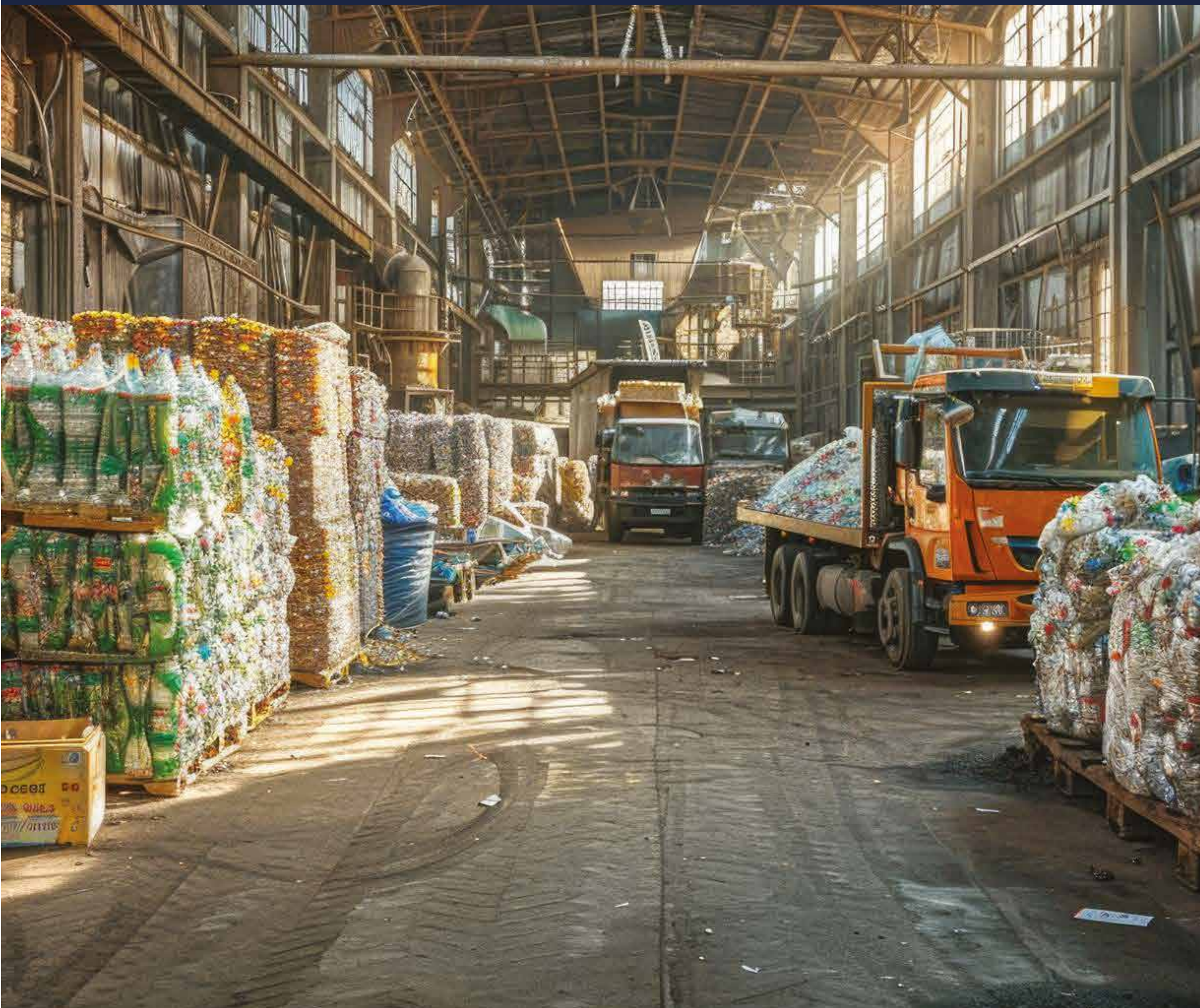
NITI Aayog

SCENARIOS TOWARDS VIKSIT BHARAT AND NET ZERO

SECTORAL INSIGHTS: WASTE

(VOL. 8)



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(VOL. 8)

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FOREWORD

India's ambitious vision of becoming Viksit Bharat by 2047 will be driven by large expansion in infrastructure development, manufacturing and urbanization. With this increase in production and urbanization, there will also be an increase in waste generation. Municipal solid waste, wastewater and landfill operations are emerging as significant sources of Greenhouse Gas emissions. Currently these account for about 2.5% of India's total Greenhouse Gas emissions. However, the waste sector's share could rise with increasing urban growth.

Waste management is not only a mitigation priority but also a development opportunity. With resource efficiency, circular material flows, and clean energy systems at its core, the sector can become a generator of value. For instance, bio-CNG can help reduce petroleum imports, recovered biogas can strengthen renewable energy supply. Likewise, processed sludge can substitute for fertilisers; and, material recovery facilities can build secondary raw-material supply chains that reduce pressure on virgin resources. These are not ancillary benefits. They are central to the competitiveness and strategic autonomy of a developed India.

NITI Aayog's comprehensive assessment concludes that there is a large potential to reduce GHG emissions from waste sector emissions. This is driven by higher source segregation and processing rates, and supported by adoption of scientific waste-management technologies such as bio-methanation, bio-CNG, and methane capture/recovery.

The transformation of the waste sector requires a dual strategy that integrates infrastructure development with behavioural change. Mobilising citizens as active partners in this transition is essential. Through sustained awareness, community engagement and lifestyle shifts, as outlined in Hon'ble Prime Minister's Mission Lifestyle for Environment (LiFE) initiative, citizens become active agents of change.

This report presents a transformative, yet achievable, low-carbon transition pathways for India's waste sector, grounded in proven solutions. I thank the NITI Aayog team led by Dr. Anshu Bharadwaj, Shri Rajnath Ram, Shri Venugopal Mothkoor, Dr. Anjali Jain and Shri Nitin Bajpai for their efforts in preparing this report. This report will go a long way realising the Hon'ble Prime Minister's vision of a Circular Economy while also aiding achievement of the Net Zero goal.

Dated: 4th February, 2026

[B.V.R. Subrahmanyam]

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List of Abbreviations

AFD	Agence Française de Développement
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
AR5	Fifth Assessment Report
ASP	Activated Sludge Process
BOD	Biological Oxygen Demand
BUR	Biennial Update Report
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CBG	Compressed Biogas
CEA	Central Electricity Authority
CH_4	Methane
CITIIS	City Investments to Innovate, Integrate and Sustain
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COP	Conference of the Parties
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CPS	Current Policy Scenario
CS	Country-Specific
CSE	Centre for Science and Environment
CT	Community Toilet
DeWATS	Decentralised Wastewater and Treatment System
DOC	Degradable Organic Carbon
DWSC	District Water Sanitation Committee
EE	Energy Efficiency
EF	Emission Factor

EIA	Environmental Impact Assessment
EPR	Extended Producer Responsibility
ETF	Enhanced Transparency Framework
EU	European Union
E-waste	Electronic Waste
FAB	Fluidised Aerobic Bioreactor
FC	Finance Commission
$F_{IND-COM}$	Factor for Industrial and Commercial co-discharged protein into the sewer system
$F_{NON-CON}$	Factor for Non-Consumed protein added to the wastewater
F_{NPR}	Fraction of Nitrogen in Protein
FOD	First Order Decay
FSSM	Faecal Sludge and Septage Management
FSTP	Faecal Sludge Treatment Plant
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GOBARdhan	Galvanizing Organic Bio-Agro Resources Dhan
GoI	Government of India
GP	Gram Panchayat
GWP	Global Warming Potential
I&D	Interception and Diversion
ICMR	Indian Council of Medical Research
IESS	India Energy Security Scenario
IPCC	Intergovernmental Panel on Climate Change
KfW	Kreditanstalt für Wiederaufbau
kWh	Kilowatt Hours
LCAP	Low Carbon Action Plan
LFG	Landfill Gas
LG	Local Government
LiFE	Lifestyle for Environment
MBBR	Moving Bed Biofilm Reactor
MBR	Membrane Bioreactor
MCF	Methane Correction Factor
MDB	Multilateral Development Bank

MLD	Million Litres per Day
MoEFCC	Ministry of Environment, Forest and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MoSPI	Ministry of Statistics and Programme Implementation
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
$MtCO_2e$	Million Tonnes of Carbon Dioxide Equivalent
Mtoe	Million Tonnes of Oil Equivalent
MU	Million Units
MWh	Mega-Watt Hour
N_2O	Nitrous Oxide
NAPCC	National Action Plan on Climate Change
NATCOM	National Communication
NCQG	New Collective Quantified Goal
NDC	Nationally Determined Contributions
NEERI	National Environmental Engineering Research Institute
NFHS	National Family Health Survey
NFSRTW	National Framework on Safe Reuse of Treated Water
NITI	National Institution for Transforming India
NIUA	National Institute of Urban Affairs
N_{SLUDGE}	Nitrogen Removed from Sludge
NSSO	National Sample Survey Organisation
NZS	Net Zero Scenario
O&M	Operations and Maintenance
OPEX	Operational Expenditure
PIB	Press Information Bureau
PPP	Public Private Partnership
PT	Public Toilet
QA	Quality Assurance
QC	Quality Control
RDD	Rural Development Department
RDF	Refused Derived Fuel
RE	Renewable Energy
SAR	Second Assessment Report
SATAT	Sustainable Alternative Towards Affordable Transportation

SBM	Swachh Bharat Mission
SBR	Sequencing Batch Reactor
SCF	Segregated Combustible Fraction
SDG	Sustainable Development Goal
SLB	Service Level Benchmark
STP	Sewage Treatment Plant
SWDS	Solid Waste Disposal Site
SWM	Solid Waste Management
TOW	Tonnes of Organic Waste
TPD	Tonnes Per Day
UASB	Upflow Anaerobic Sludge Blanket
ULB	Urban Local Body
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
UT	Union Territory
WSP	Waste Stabilisation Ponds
WtE	Waste-to-Energy

Note: *Currency Conversion: In this report, "INR" refers to Indian Rupee; USD 1 = INR 88.19 as per the exchange rate on 08 September 2025.*

Executive Summary

In 2020, India's total Greenhouse Gas (GHG) emissions (excluding Land Use, Land-Use Change, and Forestry [LULUCF]) were estimated at 2,959 million tonnes of CO_2 equivalent ($MtCO_2e$), with per capita emissions of 2.20 tCO_2e (MoEFCC, 2024). India's cumulative and per capita emissions remain far below the global average.

As a signatory to the Paris Agreement, India revised its Nationally Determined Contributions (NDCs) in 2022, committing to reduce the emissions intensity of GDP by 45% by 2030 (based on 2005 levels), promote sustainable lifestyles through the Lifestyle for Environment (LiFE) initiative, and reach Net Zero emissions by 2070 under the Panchamrit Action Plan as announced at the 26th Conference of the Parties (COP26). These commitments cover renewable energy, energy efficiency, climate resilient urbanisation, and waste management.

In 2020, the waste sector accounted for 75.64 $MtCO_2e$, which is 2.56% of India's total emissions, as per India's fourth Biennial Update Report (BUR-4). With India's urban population share expected to grow from 34.9% in 2020 to 53% in 2050, material consumption and waste generation are expected to rise significantly. In 2020, India generated 100.9 million tonnes (Mt) of municipal solid waste and 221,173 million litres per day (MLD) of domestic wastewater.

This scale of waste and wastewater generation places strain on collection systems, treatment infrastructure, and disposal pathways. Cities like Indore, Pune and Bengaluru have demonstrated the potential of modernised waste systems through robust segregation, material recovery, bio-methanation and public-private partnership (PPP) models but challenges remain across most cities: limited treatment capacity, poor segregation practices, plastic waste leakage, and large volumes of untreated wastewater. The management of wastewater, in particular, presents certain structural deficiencies, as outlined below:

- 39% sewer network coverage
- 48% of households are reliant on septic tanks; 11% on pit latrines
- Only 44.9% of sewage is collected and treated; the remaining sewage collected remains untreated due to infrastructure deficits

Policy and Planning Alignment

A climate-aligned waste transition connects India's long-term climate strategy with ongoing national missions such as Swachh Bharat Mission (SBM 2.0), Atal Mission for Rejuvenation and Urban Transformation (AMRUT), and Sustainable Development Goals (SDGs) 6, 11, 12 and 13. Strengthened governance, technology upgrades, integration of informal workers, and circularity-driven interventions underpin this transition.

This study, ***Pathways to Net Zero - Sectoral Insights: Waste***, highlights the sector's potential to contribute to India's climate commitments. It presents a detailed emissions trajectory for the waste sector, based on two distinct scenarios: **Current Policy Scenario (CPS)** and **Net Zero Scenario (NZS)**, offering insights into the transformative shifts required to meet long-term goals.

Emissions Trajectory and Modelling Framework

Emissions modelling for solid waste, domestic wastewater, and industrial wastewater has been conducted under both Current Policy Scenario and Net Zero Scenario. Both scenarios use 2020 as the baseline year and apply the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines (Volume 5: Waste), using Tier 1, Tier 2, and Tier 3 approaches with default and country-specific emission factors.

The model reflects the effects of population growth, behavioural patterns, technological adoption, and policy targets across 2050, and 2070.

Key Drivers Across Scenarios

Solid Waste Management

- **Current Policy Scenario:** Solid waste generation rises from 158.9 Mt in 2030 to 476.2 Mt by 2070 (Compound Annual Growth Rate (CAGR) of 2.8%). Treatment reaches 85% by 2050, but unmanaged fractions persist
- **Net Zero Scenario:** Per-capita waste generation is capped at 0.622 kg/day post 2047; 100% collection and segregation is achieved; treatment levels reach 85% nationally

Domestic Wastewater

- **Current Policy Scenario:** Sewer connectivity increases to 65% by 2070, with partial methane recovery
- **Net Zero Scenario:** Sewer connectivity expands to 85%, enabling universal methane capture and advanced treatment

Industrial Wastewater

- **Current Policy Scenario:** Methane recovery improves but remains partial
- **Net Zero Scenario:** 100% methane recovery by 2040, combined with treatment system upgrades by 2035

Waste Sector Emissions Outlook: Current Policy Scenario vs Net Zero Scenario

The modelling shows that without enhanced ambition, emissions from the waste sector will continue to rise steadily through 2070 under the Current Policy Scenario. Conversely, the Net Zero Scenario demonstrates a sharp decline, driven by circularity, universal collection, methane recovery, and advanced treatment technologies. In the Current Policy Scenario, emissions grow more than three times by 2070 compared to emissions in 2020, while in the Net Zero Scenario, emissions decline sharply due to the adoption of scientific waste handling techniques such as bio-methanation, bio-Compressed Natural Gas (bio-CNG), and methane recovery. Industrial and domestic wastewater emissions fall significantly in the Net Zero Scenario as both sectors adopt advanced anaerobic treatment systems, resulting in much lower emissions compared with Current Policy Scenario.

Projected Emissions Trajectory: Current Policy Scenario vs Net Zero Scenario

- **Current Policy Scenario:** Waste sector emissions grow from 75.64 $MtCO_2e$ in 2020 to 266.10 $MtCO_2e$ by 2070, an increase of 3.5x during these years
- **Net Zero Scenario:** Emissions fall to 10.9 $MtCO_2e$ by 2070, a reduction of 95.9% compared to Current Policy Scenario level

The difference between the two pathways arises from technology choice, treatment coverage, and methane recovery. Scientific disposal methods such as bio-methanation, bio-CNG, and advanced anaerobic digestion result in significantly lower methane emissions compared with conventional composting and unmanaged disposal.

Sub-sectoral Shifts: Industrial and domestic wastewater emissions decline steeply in Net Zero Scenario due to universal adoption of anaerobic treatment systems, improved sewerage, and high methane recovery. By 2070:

- **Current Policy Scenario:** Industrial wastewater (47%) dominates emissions, followed by domestic wastewater (36%) and solid waste (17%)
- **Net Zero Scenario:** Emissions from industrial wastewater reach near to zero, while the reduction in emissions from domestic wastewater and solid waste is around 98.5% and 78.8% respectively from their values in Current Policy Scenario

Key Levers for Waste Sector Transition

- Waste Reduction and Source Segregation
- Strengthening Primary and Secondary Collection and Transportation
- Processing and Resource Recovery
- Scientific Disposal and Bio-remediation
- Universal access to scientific and economical toilets
- Safe collection and transfer to treatment facilities
- Maximising treatment and faecal sludge treatment with methane recovery
- Enhancing circularity through reuse and recycling
- Implement well-managed aerobic systems (≈0 MCF)
- Enhance methane recovery from industrial wastewater
- Strengthening Technical Expertise and Capacity Building
- Advancing Climate-based Participatory Budgeting and Sustainable Procurement
- Enabling Private Sector Involvement
- Strengthening Public Awareness and Engagement
- Establishing a Robust Monitoring and Evaluation Framework

Financing sources include PPPs, carbon credits, green bonds, international climate funds, and national missions.

Conclusion

Continuing down the Current Policy Scenario pathway, India’s waste sector emissions are projected to nearly double by 2070. By contrast, the Net Zero Scenario pathway demonstrates the potential for a 95.9% reduction through circularity, advanced treatment technologies, universal methane recovery, and integrated waste systems. Aligning national missions with low-carbon pathways, strengthening urban governance, and promoting sustainable waste practices will position the waste sector as a critical enabler of India’s long-term goals of advancing environmental health, resource efficiency, and a resilient Net Zero future by 2070.

1

BACKGROUND

Background

1

India is the fastest-growing large economy and is poised to continue on this path. India aspires to be the third-largest economy by 2027 and a developed nation (Viksit Bharat) with a USD 30 trillion economy by 2047, when it marks 100 years of its independence[1].

As India's economic growth accelerates, its energy demand and corresponding environmental impact, especially Greenhouse Gas (GHG) emissions, will also increase. In 2020, India's total GHG emissions, excluding Land Use Land-Use Change and Forestry (LULUCF), were estimated to be 2,959 $MtCO_2e$, with per capita GHG emissions of 2.20 tCO_2e[2]. However, India's global carbon footprint remains significantly below the global average, both in cumulative and per capita terms (MoEFCC, 2024).

As a prominent signatory to the United Nations Framework Convention on Climate Change (UNFCCC), India submitted its first Nationally Determined Contributions (NDCs) in 2015, and updated it in 2022 (PIB, 2022). The NDCs highlight a healthy and sustainable way of living through a mass movement, Lifestyle for Environment (LiFE), to combat climate change and reduce the country's emissions intensity of its Gross Domestic Product (GDP) by 45% by 2030 from 2005 levels (UNFCCC, 2022). At the Conference of Parties, 26 (COP 26) in 2021, the Prime Minister of India announced that India would achieve Net Zero emissions by 2070 and introduced its Panchamrit Action Plan (five key climate actions). These targets were incorporated into the updated NDCs (PIB, 2022). These NDCs focus on broader climate mitigation and adaptation strategies supported by ambitious national plans, such as a thrust on renewable energy (RE) and enhancing energy efficiency (EE), climate-resilient urban centres, sustainable green transportation, networks, Swachh Bharat Mission (SBM), and the Make in India programme (MoEFCC, 2018). These efforts collectively aim to reduce the emission intensity and are not bound to sector-specific individual targets and mitigation actions (Down to Earth, 2022).

1 Press Information Bureau [PIB], 2024

2 Calculated based on population figures and national emission estimates for 2020 reported in India's Fourth Biennial Update Report (BUR-4).

Box 1: What are Nationally Determined Contributions (NDCs)?

NDCs are central to the Paris Agreement, as outlined in Article 4, and represent each country's commitment to reducing emissions and adapting to climate change impacts. Under Article 4, countries are required to prepare, communicate, and update their NDCs every five years, with each successive submission reflecting increased ambition. This submission cycle, which began with the first round of NDCs in 2020 and every five years thereafter (e.g., 2025, 2030), is designed to ensure that global climate goals are progressively achieved.

Source: *https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs.*

India's growing economy material and product footprint. The expansion of GDP by nearly eight-fold will lead to an enormous increase in industrial and waste output. For example, the annual material consumption increased from 1.18 billion tonnes to 7 billion tonnes between 1970 and 2015 and is expected to reach 14.2 billion tonnes by 2030 (Ministry of Housing and Urban Affairs [MoHUA], 2021). This has significantly increased waste generation and GHG emissions over the years. In 2020, the waste sector contributed to only 2.56% of India's total GHG emissions, yet its emissions have increased by more than 3 times between 1994 and 2020 (MoEFCC, 2024). Wastewater treatment and discharge (domestic and industrial) contributed to 73.9% of the sector's emissions, while solid waste disposal contributed 26.1% (MoEFCC, 2024). Methane (CH_4) is the primary GHG emitted from solid waste disposal, as well as from domestic and industrial wastewater treatment and discharge (ICLEI South Asia, 2023). India's urban population is set to reach 53% by 2050, compared to 35% in 2020[3]. This rapid urbanisation, along with population growth, economic development, and changing lifestyles, is expected to substantially increase the quantum of municipal solid waste (MSW) and domestic and industrial wastewater, thereby increasing the emissions.

The waste sector is emerging as a critical focus area due to its significant potential to reduce GHG emissions, particularly CH_4, with its higher warming potential than CO_2. Therefore, strengthening capacities and governance mechanisms are essential to integrate low-carbon solutions into the planning, design, implementation, and financing of Municipal Solid Waste (MSW) and wastewater management systems. This would facilitate achieving overall climate-compatible development that is aligned with the targets of national programmes. This includes programmes such as Swachh Bharat Mission (SBM) and Atal Mission for Rejuvenation and Urban Transformation (AMRUT), but also with global commitments such as the SDG–6

3 ICLEI South Asia analysis based on the population data shared by NITI Aayog.

(Clean Water and Sanitation), SDG-7 (Affordable and Clean Energy), SDG-11 (Sustainable Cities and Communities), SDG-12 (Responsible Consumption and Production), and SDG-13 (Climate Action).

In this context, NITI Aayog undertook a detailed assessment for the waste sector until 2070. This involved a baseline assessment and development of two scenarios–Current Policy Scenario (CPS) and Net Zero Scenario (NZS), using 2020 as the baseline year.

2

OVERVIEW OF WASTE SECTOR IN INDIA

Overview of the Waste Sector in India

2

There are complex challenges in managing diverse waste streams, including Municipal Solid Waste (MSW), wastewater, plastic waste, bio-medical waste, construction and demolition debris, hazardous waste, and electronic waste (e-waste). Rapid urbanisation, changing consumption patterns, and population growth have significantly increased waste generation, thus putting pressure on existing waste management systems. Untreated solid or liquid waste leads to environmental degradation, contamination of water bodies, and public health risks.

India is steadily advancing towards sustainable waste management through strengthened regulatory frameworks, decentralised solutions, innovative technologies, and an emphasis on public-private partnerships. Ongoing initiatives like the Swachh Bharat Mission (SBM)–Urban/Gramin, Smart Cities Mission (SCM), City Investments to Innovate, Integrate and Sustain 2.0 (CITIIS 2.0) and AMRUT are pivotal in tackling diverse waste management challenges. Policies such as the Solid Waste Management Rules 2016, Plastic Waste Management Rules 2016, and E-Waste Management Rules 2022 also provide essential support to state and local governments for more efficient waste management. With a growing focus on circular economy principles and resource recovery, India's waste sector is evolving to align with environmental sustainability goals.

2.1 Existing Solid Waste Management (SWM) Practices in India

Solid Waste Management (SWM) is a cornerstone of environmental sustainability. Effective waste handling and management can safeguard public health, mitigate environmental pollution, and conserve natural resources. This section delves into the state of SWM in the country, exploring key aspects such as trends in waste generation, collection, transportation, treatment, and disposal methods. It highlights the gaps in infrastructure, limited adoption of sustainable technologies, and insufficient segregation and recycling practices.

Solid Waste Generation

The rising volume of waste generated in India is driven by population growth, urbanisation, lifestyle changes, and evolving consumption patterns. Urban areas contribute disproportionately to waste generation due to their dense population, industrial activity, and commercial development. India generated an estimated total of 101 Mt of solid waste in 2020[4]. Of this, 61% ended up in landfills, and the remaining primarily underwent treatment, processing and incineration.

In 2020, of the total waste processed in India, 28.5% was composted, 0.9% treated through bio-methanation, 0.02% converted to bio-CNG, 0.5% waste recycled via Material Recovery Facility (MRF), and 2.8% incinerated, including through Refuse Derived Fuel (RDF) and palletisation. In terms of composition, Municipal Solid Waste (MSW) consisted of approximately 50% organic or compostable material, 25% recyclables, 15% non-recyclable combustibles, and 10% miscellaneous waste as of 2020 (see Figure 2.1) (Centre for Science and Environment [CSE], 2022).

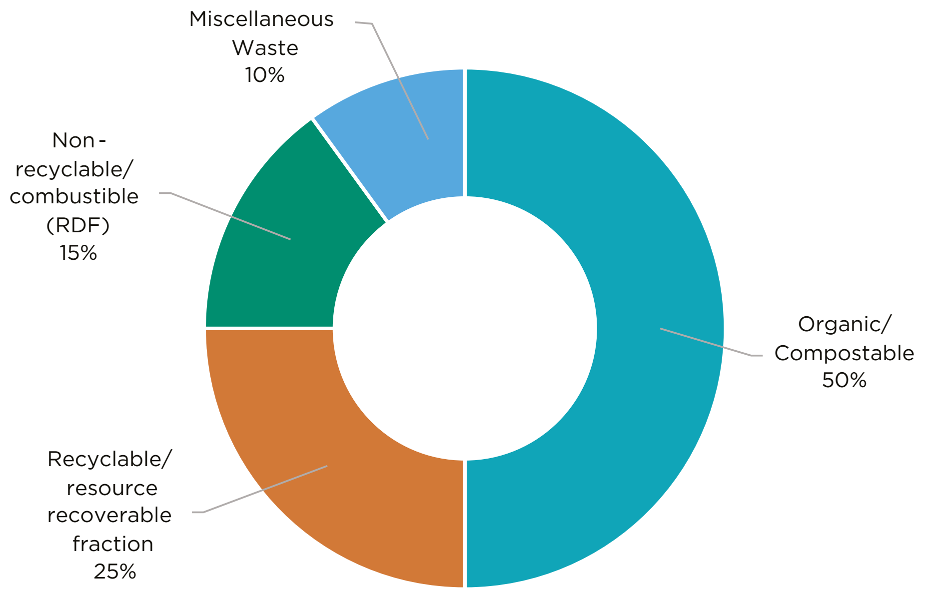

Figure 2.1: Composition of solid waste in India, 2020

Source: *Toolkit Preparing City Solid Waste Action Plan under Swachh Bharat Mission (SBM 2.0), Centre for Science and Environment (CSE)*

Waste Collection and Transportation

In India, local authorities are primarily responsible for collecting and transporting solid waste through primary and secondary collection methods. As per Swachh Bharat Mission (Urban) 2.0, 97% of Indian cities have implemented door-to-door waste collection systems, and initiatives to promote source segregation are gaining traction, but with varying levels of success.

4 ICLEI South Asia analysis based on the data provided by NITI Aayog, NEERI, and data sourced from India Energy Security Scenario (IESS) 2047.

Segregated waste is typically divided into biodegradable, recyclable, and non-recyclable categories. However, rural areas have minimal waste segregation, although programmes like the Swachh Bharat Mission (Gramin) are beginning to raise awareness about sustainable waste management practices.

In India, compactors, tippers, and mini-trucks transport waste from collection points to treatment or disposal sites. Larger cities often rely on waste transfer stations where waste is compacted to optimise logistics before it is transported to its destination. However, inefficiencies in transportation frequently leave waste uncollected in certain urban pockets.

Collection and transportation of waste have various gaps, including an inadequate workforce, gaps in infrastructure for waste storage at source, and limited implementation of door-to-door collection services. These services are often facilitated by municipal workers or private contractors, but they lack synchronisation with transfer depots and transportation facilities. As a result, informal secondary collection points, often referred to as garbage vulnerable spots, tend to develop, where waste that does not make it to the formal collection system ends up accumulating.

Processing and Disposal

India is gradually adopting advanced waste treatment technologies such as composting, bio-methanation, bio-Compressed Natural Gas (bio-CNG), and Material Recovery Facility (MRF) to segregate recyclable materials like plastics, metals, and paper. Many cities have successfully implemented waste management initiatives through PPP models. Indore and Pune, for example, have engaged private players in waste collection, transport, and treatment operations. Indore's composting and bio-methanation plants, operating under PPP agreements, are noteworthy examples of sustainable and scalable waste management practices. Sanitary landfills are used to dispose post-treatment residual waste. In other cities and towns, however, inadequate infrastructure forces most of them to rely on open dumping, which poses significant environmental and health risks. Emerging trends, technology and innovation in cities indicate a shift toward decentralised waste management solutions. Localised approaches such as home composting and small-scale treatment units are being adopted to reduce dependency on transportation and landfill sites.

Integrating informal waste pickers and recyclers into formal systems has improved recycling efficiency and provided livelihood opportunities. Additionally, technological advancements have led to GPS-enabled vehicles for waste collection and sensor-based monitoring at landfills. Despite these advancements, India's solid waste management remains a mix of progress and persistent challenges. Urban areas are moving towards innovative and technology-driven solutions, while rural areas require more investment in infrastructure, formalisation of waste systems, and community awareness. Waste treatment facilities are less developed in rural areas. Composting pits for organic waste are commonly used at the household or community level, and small-scale biogas plants are found in some regions. However, most rural waste is openly dumped, leading to pollution and contamination of nearby water sources.

Box 2: Key Sources of Solid Waste

Solid waste can be broadly categorised into several types, based on their sources:

Urban Areas:

- **Household Waste**: Residential waste constitutes a significant portion of urban waste. It includes organic waste (food waste), packaging materials, plastics, metals, and other non-biodegradable items.
- **Commercial Waste**: This includes waste generated by markets, restaurants, shopping malls, offices, and other commercial establishments. It is often a mix of organic and inorganic materials.
- **Construction and Demolition Waste**: Large-scale construction activities in urban areas produce a significant amount of waste, including concrete, wood, and metal scraps.
- **E-waste**: Urban areas, with their greater access to technology, are major producers of electronic waste, which includes outdated and broken electronic devices.

Rural Areas:

- **Agricultural Waste**: Agricultural activities are main sources of waste such as crop residues, animal waste, and unused or discarded materials like plastics used in farming.
- **Household Waste**: Like urban areas, rural households too generate organic waste (food scraps) and inorganic waste (plastic wrappers, broken items).
- **Animal Waste**: Livestock farming produces large amounts of manure, which, if improperly managed, can cause pollution.

2.2 Existing Domestic Wastewater Management in India

Effective domestic wastewater management is vital to safeguard public health, maintain water quality, and support ecosystem resilience. This section looks at prevalent practices, identifies key challenges, and explores potential strategies to enhance wastewater management systems across India.

Current Status of Domestic Wastewater Management

An estimated 221,173 million litres per day (MLD) of wastewater was generated in India in 2020[5]. Population growth, urbanisation, and economic activities have led to a significant increase in wastewater generation. Wastewater management remains a critical challenge due to

5 ICLEI South Asia analysis based on the data provided by NITI Aayog, NEERI, and data sourced from India Energy Security Scenario (IESS) 2047.

infrastructure and operational gaps, particularly in sewage collection, treatment, and disposal in India.

In India, around 47% of households used septic tanks as of 2020, and 33% had access to centralised sewerage systems. Of the sewage collected, 55.1% remained untreated due to infrastructure gaps (MoSPI, 2023). Among treatment facilities, 63.75% used aerobic treatment solutions, and the remaining 36.25% used anaerobic processes (CPCB, 2021). The lack of centralised infrastructure leads to large amounts of uncollected and untreated wastewater.

2.3 Key Policies and Regulations

India's waste management ecosystem is governed by a comprehensive suite of regulations and policies designed to manage waste generation, segregation, collection, transportation, treatment, and disposal. This section reviews the existing regulatory landscape, key policies, and national level programme and projects. Box 3 below describes key policies and regulations for India's waste sector.

Box 3: Key Policies and Regulations

Solid Waste Management Rules, 2016 (Amended in 2020): The Solid Waste Management (SWM) Rules 2016 mandate the segregation of waste at source into biodegradable, non-biodegradable, and hazardous categories and emphasise door-to-door collection, scientific processing, and disposal of waste. The rules outline the responsibilities of key stakeholders, including the Ministry of Environment, Forest and Climate Change (MoEFCC), the Ministry of Housing and Urban Affairs (MoHUA), relevant departments, district collectors, the secretary in charge of urban development in the state, pollution control boards, urban local bodies (ULBs), waste generators, waste processing units, and facilities that utilise processed waste (such as cement plants using Refused Derived Fuel (RDF) in managing Municipal Solid Waste (MSW). The 2020 amendment notifies that the rules shall apply to villages with population of over 3000 as well (Central Public Health Environmental Engineering Organisation (CPHEEO), 2016).

Plastic Waste Management Rules, 2016 (Amended 2021): It aims to reduce the environmental impact of plastic waste by emphasising source segregation, recycling, and environmentally sound disposal. Key provisions include Extended Producer Responsibility (EPR), which makes producers, importers, and brand owners accountable for managing plastic waste. The 2021 and 2022 amendments strengthened these regulations by targeting single-use plastic items, specifying a phased ban on products with low utility and high littering potential. They also introduced clearer EPR guidelines and mandated plastic producers to submit action plans for waste management (CPCB, 2021).

National Policy on Faecal Sludge and Septage Management, 2017: It aims to ensure safe and sustainable sanitation practices. It addresses the challenges of managing human waste from on-site sanitation systems like septic tanks and pit latrines. The policy emphasises the importance of proper collection, transportation, treatment, and disposal of faecal sludge and septage to prevent environmental pollution and protect public health (Ministry of Urban Development, 2017).

National Framework on the Safe Reuse of Treated Water (NFSRTW): The Ministry of Jal Shakti published the NFSRTW in 2021 with the vision of ensuring widespread and safe reuse of treated water in India (Ministry of Jal Shakti, 2022).

2.4 National Level Programmes and Projects

India has launched several national-level programmes and projects to address challenges in solid waste management, domestic wastewater treatment, and industrial effluent control. Key initiatives include the Swachh Bharat Mission (SBM), Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Galvanizing Organic Bio-Agro Resources Dhan (GoBARDHAN), and Sustainable Alternative Towards Affordable Transportation (SATAT). These programmes together lay the institutional and infrastructural groundwork to support India's long-term sustainability and climate goals. Box 4 below describes the national level programmes and projects for India's waste sector.

Box 4: National Level Programmes and Projects

Atal Mission for Rejuvenation and Urban Transformation (AMRUT) and AMRUT 2.0: These are the Government of India's flagship programmes that aim to improve urban infrastructure and quality of life. AMRUT, launched in 2015, focuses on providing amenities like water supply, sewerage, urban transport, and green spaces in 500 selected cities. AMRUT 2.0, launched in 2021, builds upon the foundation of AMRUT, with a focus on providing universal water supply and sewerage coverage in all statutory towns (PIB, 2022).

Swachh Bharat Mission-Urban (SBM-Urban): It is a nationwide cleanliness campaign launched by the Government of India in 2014. SBM 2.0 was launched in 2021. The mission aims to achieve 100% sanitation coverage in India by eliminating open defecation and promoting Solid Waste Management (SWM). As a key outcome of the mission, 1,140 lakh tonnes of legacy waste have been bio-remediated from dump sites, which accounts for 48% of the total legacy waste across 2,429 dump sites nationwide (MoHUA, 2021).

Swachh Bharat Mission-Gramin (SBM-Gramin): Swachh Bharat Mission Gramin and Gramin 2.0 (SBM-G 2.0) focus on sustaining the achievements of its SBM (Gramin) phase, while addressing gaps in sanitation. The mission prioritises solid and liquid waste management, recognising sanitation as a crucial factor for health, dignity, and well-being (Ministry of Jal Shakti, 2021).

City Investments to Innovate, Integrate and Sustain 2.0 (CITIIS 2.0): The Government of India approved the CITIIS 2.0 program on 31 May 2023. Conceived by the Ministry of Housing and Urban Affairs (MoHUA) in partnership with the Agence Française de Développement (AFD), Kreditanstalt für Wiederaufbau (KfW), the European Union (EU), and the National Institute of Urban Affairs (NIUA), the program will run for four years (2023–2027). The CITIIS 2.0 program is supporting 18 cities in implementing circular economy, integrated waste management and climate-resilient urban projects. It focuses on city-level innovation, state-level capacity building, and national-level knowledge sharing to drive sustainable urban transformation (NIUA, 2023).

Smart Cities Mission (SCM): The Smart Cities Mission in India prioritises sustainable waste management. Key initiatives focus on scientific waste management practices, including segregation at source, waste-to-energy solutions, and recycling programs to minimise landfill dependence.

GoBARDHAN (Galvanizing Organic Bio-Agro Resources Dhan): The Ministry of Jal Shakti launched this initiative under Swachh Bharat Mission (SBM) to promote the management of organic waste and improve the management of solid waste. It primarily focuses on converting organic waste from agricultural, livestock, and urban waste into bioenergy, including biogas, and organic fertilisers (Ministry of Jal Shakti, 2023).

Sustainable Alternative Towards Affordable Transportation (SATAT): The SATAT scheme, launched by the Government of India in 2018, aims to promote the production and adoption of Compressed Biogas (CBG) as an alternative fuel for transportation (Ministry of Petroleum and Natural Gas, 2023).

2.5 India's Baseline GHG Emissions

As part of its global climate commitments, India has been regularly reporting its greenhouse gas (GHG) emissions through the National Communications (NATCOMs) and Biennial Update Reports (BURs). In addition, under the Enhanced Transparency Framework (ETF) established by the Paris Agreement, all Parties are now mandated to submit a Biennial Transparency Report (BTR) that provides transparent and consistent updates on national progress toward climate goals.

India submitted its Fourth Biennial Update Report (BUR-4) in 2024, which includes its economy-wide emissions for 2020 (MoEFCC, 2024). The BUR-4 reports Waste sector emissions for three sub-sectors in line with IPCC Guidelines: i) solid waste management, which includes disposal, biological treatment, and incineration; ii) domestic wastewater treatment and discharge; and iii) industrial wastewater treatment and discharge.

As reported in India's BUR-4, GHG emissions from the waste sector in 2020 were estimated at 75.64 $MtCO_2e$, accounting for 2.56% of the country's total emissions, and 3.4% higher than in 2019 (MoEFCC, 2024). Although the sector's contribution to overall economy-wide emissions remains modest, with rapid urbanisation, population growth, and shifts in consumer behaviour, it is expected to increase further, though steadily. The sub-sectoral and gas-wise breakup of India's waste sector emissions is presented in Table 2.1 below.

Table 2.1: India's GHG emissions from waste in 2020

Sub-Sector	CO_2 Emissions ($MtCO_2$)	CH_4 Emissions ($MtCH_4$)	N_2O Emissions (MtN_2O)	Total ($MtCO_2e$)
Solid Waste Management	0.479	0.917	-	19.75
Solid Waste Disposal	-	0.911	-	19.14
Biological treatment of solid waste	-	0.006	-	0.127
Incineration of waste	0.479	-	-	0.479
Domestic Wastewater Treatment & Discharge	-	0.772	0.0578	34.13
Industrial Wastewater Treatment & Discharge	-	1.036	-	21.76
Total (Waste)	**0.479**	**2.726**	**0.0578**	**75.64**

Note: *The estimate considers a 100-year time-horizon Global Warming Potential (GWP) values from the IPCC Second Assessment Report (AR2).*

As depicted in Table 2.1, wastewater treatment and discharge were the most significant contributors to GHG emissions, accounting for approximately 74% of the sector's total emissions, i.e., 55.89 $MtCO_2e$. Of this, domestic wastewater accounted for 34.13 $MtCO_2e$ of the emissions (about 45% of the sectoral emissions), while industrial wastewater contributed about 21.76 $MtCO_2e$ (about 29% of the sectoral emissions). This dominant share of the wastewater subsector reflects India's continued reliance on methane-intensive sanitation systems, such as septic tanks and pit latrines in households, along with high organic loads and inefficient wastewater treatment in industries. The data also underscores the lack of methane recovery systems in the wastewater sector and reliance on aerobic treatment systems.

Emissions from solid waste in 2020 were estimated at 19.75 $MtCO_2e$, accounting for the remaining 26% of sectoral emissions. Solid waste disposal is the predominant driver of emissions, accounting for approximately 97% of the sub-sector emissions (i.e., 19.14 $MtCO_2e$). In comparison, emissions from biological treatment and incineration of solid waste were limited to 0.127 $MtCO_2e$ and 0.479 $MtCO_2e$, respectively. This reflects the dominance of open dumping practices and the limited availability of scientifically managed sanitary landfills nationwide.

In terms of GHGs (CO_2e), methane (CH_4) was the dominant gas, accounting for 75.7% of total waste-sector emissions in 2020. In contrast, Nitrous oxide (N_2O) accounted for 23.7% of the emissions, and the remaining 0.6% was attributed to carbon dioxide (CO_2) emissions, originating primarily from the incineration of solid waste (see Figure 2.3).

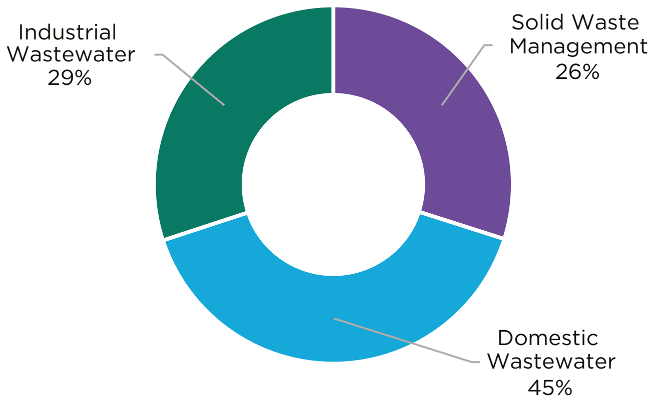

Figure 2.2: Subsector-wise share of GHG emissions in India's waste sector in 2020

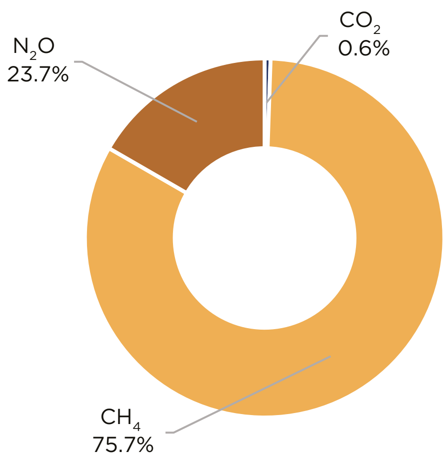

Figure 2.3: Share of green house gases in India's waste sector emissions in 2020

Overall, India's 2020 waste sector emissions profile underscores that wastewater treatment and disposal systems accounted for the majority of emissions, followed by solid waste disposal. The baseline emissions profile provides an overview of the sector's current emissions landscape. However, as India progresses toward its Net Zero emissions goal, it becomes essential to understand how policies and additional measures could influence future emissions levels. In this context, climate modelling has been undertaken for the waste sector up to 2070 under two scenarios, Current Policy Scenario (CPS) and Net Zero Scenario (NZS), to assess the potential trajectory of waste emissions. The detailed methodology and results of this modelling exercise are presented in the subsequent sections.

3

METHODOLOGY FOR SCENARIO MODELLING

Methodology for Scenario Modelling

3

3.1 Modelling Approaches

There are various analytical models available for projecting waste sector emissions and understanding trends in waste generation, treatment technologies, and mitigation strategies. The study has adopted the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, utilising Tier 1, Tier 2, and Tier 3 approaches across sub-sectors (see Table 3.1). A combination of top-down and bottom-up approaches has been used to estimate emissions. Both default and country-specific emission factors (EFs) have been utilised as appropriate.

The **top-down approach** relies on macro-level statistics like population, per capita waste generation, and economic parameters. Top-down models typically apply Tier 1 emission factors from the IPCC guidelines and are appropriate for national-level estimations or general projections. However, top-down models lack granularity to account for specific technologies, treatment pathways, or regional conditions. **Bottom-up approaches,** on the contrary, are modelled with disaggregated, detailed datasets that include the treatment and disposal pathways (e.g. composting, anaerobic digestion, incineration, landfill for solid waste), and system parameters such as process efficiencies and recovery activities. The bottom-up models enable technology-level assessments, scenario analysis, and relatively more accurate forecasts of emissions. They are generally aligned with Tier 2 and Tier 3 methodologies, providing increased accuracy and policy alignment.

Box 5: Methodological Approach by Sub-Sector

Solid Waste

Solid Waste Disposal: Emissions from solid waste disposal sites (SWDS) have been estimated using Tier 1 and Tier 2 approaches. The First Order Decay (FOD) model, as outlined in the 2006 IPCC Guidelines, has been employed to estimate methane emissions from the anaerobic decomposition of degradable organic carbon (DOC) in solid waste over time. Key input parameters include the fraction of degradable organic matter, methane generation rate, and site-specific management factors. Default decay constants and methane correction factors (MCF) have been used for calculations.

Biological Treatment of Solid Waste: Emissions from biological treatment, including composting and anaerobic digestion, have been estimated using a Tier 1 approach. Activity data for biological treatment processes are derived from national datasets. Emission calculations have been based on default emission factors specified in the 2006 IPCC Guidelines.

Waste Incineration: A Tier 3 approach has been applied for estimating emissions from waste incineration as per the IPCC guidelines. Activity data, including the fraction of waste incinerated is integrated with combustion characteristics such as combustion efficiency and carbon oxidation factors. Emissions have been calculated using default emission factors specified in the 2006 IPCC Guidelines.

Wastewater

Domestic Wastewater: Methane emissions from domestic wastewater have been estimated using the Tier 1 approach based on population data and wastewater generation rates. Key parameters include methane correction factors, biochemical oxygen demand (BOD), and the fraction of wastewater treated anaerobically. Nitrous oxide (N_2O) emissions have been estimated using a Tier 1 approach, applying nitrogen content in wastewater based on national protein consumption data. Emission factors for indirect N_2O emissions from wastewater discharge have been sourced from the IPCC Guidelines.

Industrial Wastewater: Industrial wastewater CH_4 emissions have been estimated using the Tier 1 approach, incorporating a top-down methodology for key industrial sectors. Methane generation potential is derived using sector-specific chemical oxygen demand (COD) or BOD values. Activity data on industrial wastewater discharge and treatment pathways have been integrated with IPCC default emission factors, considering the lack of detailed plant-level or process-specific data.

Table 3.1: Type of emission factor and level of methodological tier adopted for national-level GHG estimates for waste sector

IPCC ID	GHG source & sink categories	CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor
4A	Solid Waste Disposal	T1, T2	D, CS	—	—
4B	Biological Treatment of Solid Waste	T1	D	T1	D
4C1	Waste Incineration	T3	D	T3	D
4D1	Domestic wastewater treatment and discharge	T1	D	T1	D
4D1	Industrial wastewater treatment and discharge	T1	CS	—	—

Notes: *T: Tier; CS: Country-specific; D: IPCC default*

A summary of the data sources utilised to estimate emissions is presented in Table 3.2 below.

Table 3.2: Data sources for waste sector GHG estimates

IPCC ID	GHG source & sink categories	Data Sources
4A	Unmanaged Waste Disposal Sites	◆ Central Pollution Control Board (CPCB) ◆ National Environmental Engineering Research Institute (NEERI) ◆ Central Public Health Environmental Engineering Institute (CPHEEO) ◆ NITI Aayog ◆ Census of India ◆ Ministry of Housing and Urban Affairs (MoHUA) ◆ Swachh Bharat Mission (SBM) (Urban and Gramin) ◆ IPCC 2006 Guidelines on national emission inventories
4B	Biological Treatment of Solid Waste	◆ IPCC 2006 Guidelines on national emission inventories ◆ CPCB ◆ NEERI ◆ SBM
4C1	Waste Incineration	◆ IPCC 2006 Guidelines on national emission inventories ◆ CPCB ◆ NEERI

IPCC ID	GHG source & sink categories	Data Sources
4D1	Domestic wastewater treatment and discharge	◆ CPCB ◆ Census of India ◆ National Sample Survey Organisation (NSSO) ◆ NEERI ◆ India Third National Communication (NATCOM-III) ◆ Biennial Update Report (BUR-III/IV) ◆ Indian Council on Medical Research (ICMR) ◆ IPCC 2006 Guidelines on national emission inventories
4D1	Industrial wastewater treatment and discharge	◆ NITI Aayog ◆ CPCB ◆ Economic Survey of India ◆ Department of Animal Husbandry, Dairying & Fisheries, Government of India ◆ Department of Food and Public Distribution, Ministry of Consumer Affairs, Food and Public Distribution, Government of India (GoI) ◆ NEERI ◆ NATCOM-III ◆ BUR – III/IV ◆ IPCC 2006 Guidelines on national emission inventories

3.2 Data Projections

National-level projections extended to 2070 relied on a combination of interpolation, extrapolation, and macro-level modelling. Key elements of the methodology used are:

- **Activity Data Projections:** Population growth trends, combined with national averages for per capita waste generation, BOD levels, per capita protein consumption.
- **Technological Assumptions:** Incremental improvements in waste processing and treatment have been modelled, reflecting anticipated advancements up to 2070.
- **Interpolation for Data Gaps:** National datasets were used to interpolate missing historical data, ensuring consistent trends across time periods.
- **Elasticity of Production:** For industrial emissions, average elasticity of production was calculated, which was used to forecast industrial production until 2070. This methodology leverages economic trends and elasticity models to forecast future industrial output based on macroeconomic changes.[6]
- **Linear and Target-Based Approaches:** Expansion in treatment capacity and reductions in untreated sewage followed linear trajectories, aiming for zero untreated discharge.

6 Refer Annexure II – Part C for the detailed methodology on industrial production projections using elasticity method.

3.3 Scenarios Modelled

Based on consultations with the working group comprising officials from MoEFCC, NEERI, and NITI Aayog officials, two scenarios were developed to analyse emissions from India's waste sector. Annexure II contains detailed description of various data sources and assumptions used in these scenarios. The broad definition of the two is as follows:

- **Current Policy Scenario (CPS):** It represents projected GHG emissions based on current trends, policies, and planned improvements. It reflects how emissions are likely to evolve if India continues its current trajectory, gradually adopting cleaner technologies and strengthening current waste management practices.
- **Net Zero Scenario (NZS):** It outlines a transformative pathway to achieve Net Zero emissions in India's waste sector by 2070, aligning with the country's broader climate goals. The scenario builds on national policies, plans and initiatives, pushing for more ambitious targets that go beyond current national commitments. This scenario aims to enable a decisive shift toward a circular economy and sustainable waste management practices.

Key policies, plans, and initiatives considered for Current Policy Scenario and Net Zero Scenario for waste sector emission modelling include the following:

- Nationally Determined Contributions (NDC), 2022
- Swachh Bharat Mission (SBM) 2.0 (Urban and Gramin)
- Atal Mission for Rejuvenation and Urban Transformation (AMRUT) 2.0 (AMRUT 2.0)
- Framing Guidelines for Model Land Uses, Development Controls, and Service Level Benchmarks with Appropriate Enforcement Mechanisms for Rurban Clusters
- Municipal Solid Waste Management Manual 2016 by the Central Public Health and Environmental Engineering Organisation (CPHEEO, MoHUA)
- Plastic Waste Management Rules, 2016 (Amended 2021)
- National Policy on Faecal Sludge and Septage Management, 2017
- National Framework on Safe Reuse of Treated Water, 2022
- Draft Liquid Waste Management Rules 2024, Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India (MoEFCC, 2024)
- G20 New Delhi Leaders' Declaration, 2023 (Government of India, 2023)
- Sustainable Alternative Towards Affordable Transportation (SATAT) scheme
- Galvanizing Organic Bio-Agro Resources Dhan (GOBARdhan) Initiative under SBM
- City Investments to Innovate, Integrate and Sustain 2.0 (CITIIS 2.0)

4

RESULTS AND INSIGHTS FROM SCENARIO ANALYSIS

4

Results and Insights from Scenario Analysis

India's waste sector is projected to undergo significant transformation between 2030 and 2070 as demographic expansion, rising material consumption, and industrial growth accelerate the generation of solid waste, domestic wastewater, and industrial effluents. While each subsector behaves differently, the overall trend points to a steady increase in waste generation, which in turn shapes emissions trajectories under both Current Policy Scenario and Net Zero Scenario.

4.1 Future Scenario of Waste Sector

Integrated Outlook for Waste Generation (2030 – 2070)

Solid waste generation, domestic wastewater discharge and industrial wastewater volumes follow distinct growth trajectories but together indicate increasing pressures on India's waste systems.

Solid waste generation is projected to increase steadily from 158.9 Mt in 2030 to 333.3 Mt in 2050 and 476.2 Mt in 2070, reflecting both population growth and evolving patterns of consumption.

Domestic wastewater generation is also projected to increase from 240,684 Million Litres per Day (MLD) in 2030 to 265,791 MLD in 2070. The steepest rise is expected before 2050, in line with demographic growth, while stabilisation post-2050 reflects projected trends in population and economic development.

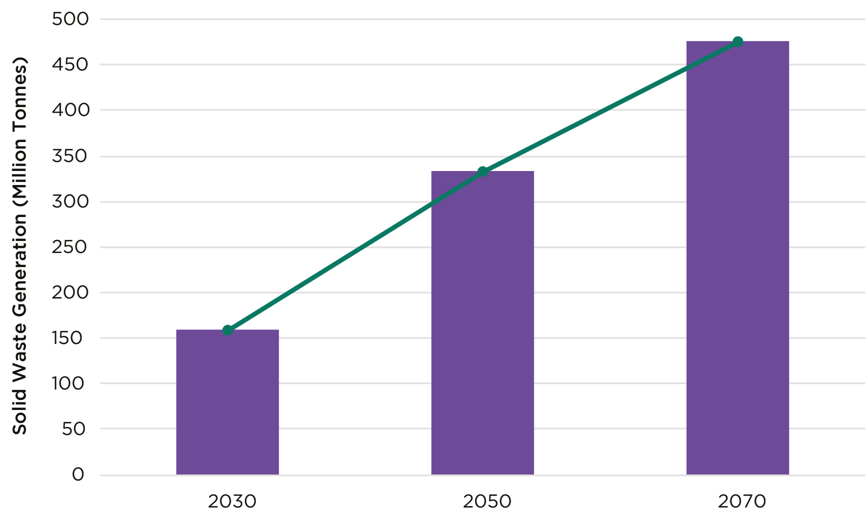

Figure 4.1: Solid waste generation projections in India (Million Tonnes)

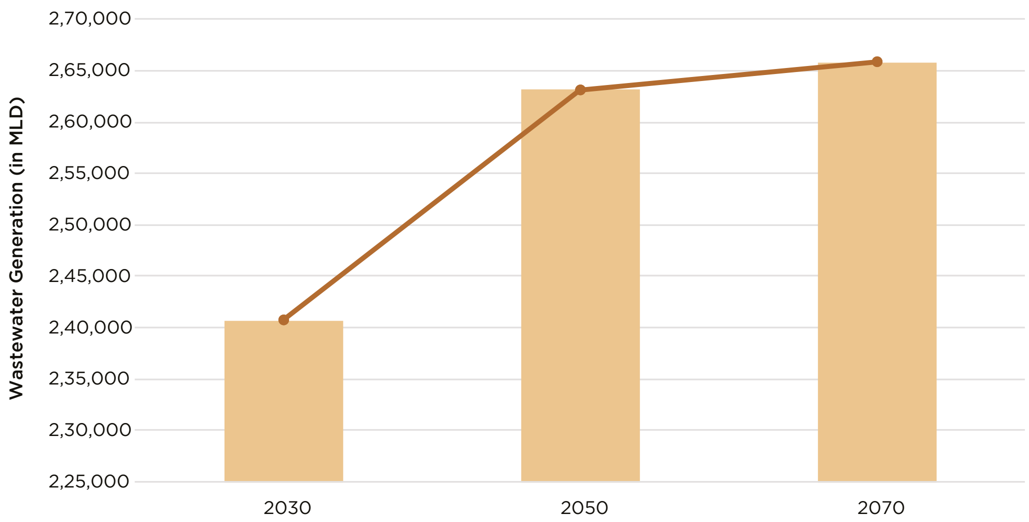

Figure 4.2: Domestic wastewater generation projections in India (Million Litres per Day)

Industrial wastewater volumes are projected based on increasing production across eight major industrial sectors[7] that includes dairy, petroleum, sugar, fish processing, textiles, paper and pulp, fertilisers, and meat (see figure 4.3). The list of sectors is based on the Fourth Biennial Update Report (BUR-IV) and India's Third National Communication (NATCOM-III) (MoEFCC, 2024; MoEFCC, 2023). These industries are significant contributors to organic wastewater and methane emissions. Production across all eight sectors is expected to expand

7 The Iron and Steel, Rubber, and Chlor-Alkali industries were excluded from the estimates because their Methane Correction Factor (MCF) is considered to be zero in national inventories, including NATCOMs and BURs. A zero MCF indicates that the processes in these industries operate under fully controlled aerobic conditions and do not produce methane. As a result, methane emissions from these industries are either zero or negligible and are therefore excluded from the emission estimates. Additionally, the alcohol, plastic and resins, soap and detergents, starch production, vegetable oils, vegetable, tannery, fruits and juices, and coffee industries have also not been included in the analysis due to a lack of data and their minimal contribution to total waste emissions.

steadily, leading to commensurate increases in effluent volumes. Annexure II – Part C provides a summary of the data sources, methodological approach, and assumptions used for industrial production projections. See the projected industrial production across these sectors below.

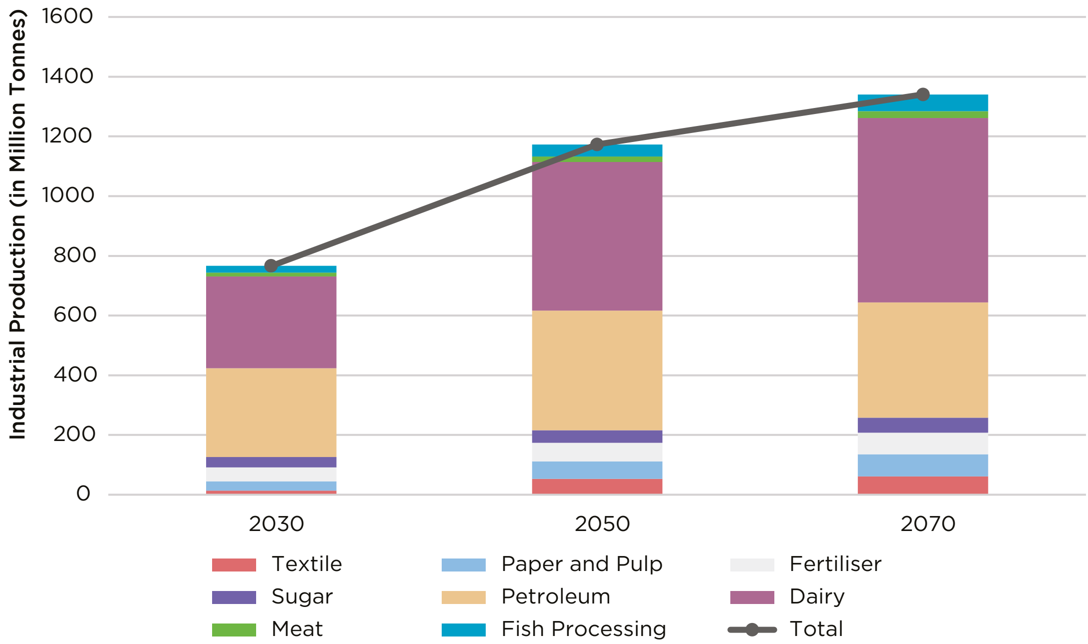

Figure 4.3: Industrial production projections in India

This upward trend in industrial activity is expected to lead to an increase in industrial wastewater volumes and the associated GHG emissions. As shown in Figure 4.4, Industrial wastewater generation is projected to reach 68,685 MLD by 2070 (more than 3.7 times the 2020 level), highlighting the need for effective treatment systems and emissions mitigation strategies.

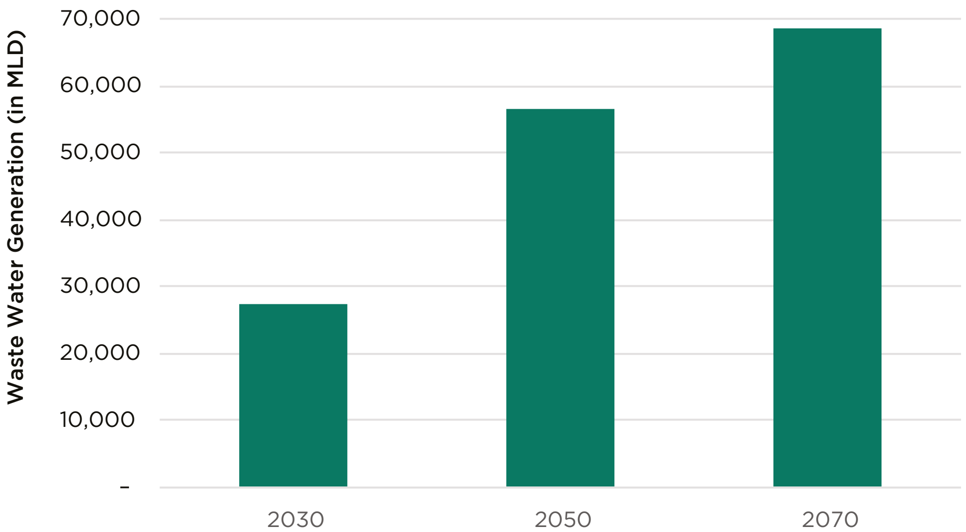

Figure 4.4: Industrial wastewater generation projections in India

4.2 Emissions Trajectory and Modelling Framework

The emissions modelling evaluates how solid waste, domestic wastewater, and industrial wastewater contribute to overall GHG emissions under both Current Policy Scenario and Net Zero Scenario. The modelling is based on a consistent methodological framework using the IPCC 2006 Guidelines (Volume 5: Waste) and Tier 1, Tier 2, and Tier 3 approaches, depending on data availability. Emissions are estimated for CO_2, CH_4 and N_2O. Factors influencing emissions include waste quantities, treatment pathways, technology performance, methane correction factors, methane recovery and population and economic activity trends.

Common assumptions applied across both scenarios, include the use of 2020 as the baseline year, projection years of 2030, 2050 and 2070, and activity data based on national datasets, BUR-IV, NATCOM-III, NEERI, CPCB and other official sources listed in Annexure II.

The detailed parameters for each subsector that feed directly into the modelling are presented below (See Table 4.1, 4.2 and 4.3).

Table 4.1: Targets for municipal solid waste

	2050		2070	
Population (Billion)	1.6		1.62	
	Current Policy Scenario		Net Zero Scenario	
Strategies	**2050**	**2070**	**2050**	**2070**
Per Capita Waste Generation (kg/ Capita/Day)	0.775	1.004	0.622	0.622
Waste Disposal (%)	15	15	15	15
Waste Processing (%)	85	85	85	85
Target Setting for Solid Waste Processing (% of waste processed)				
Composting (%)	40	40	20	10
Bio-methanation[8] (%)*	5	5	15	17
Bio-CNG (%)	2	2	12	20
Waste Incineration/RDF (%)	15	15	15	15
MRF (Recycling) (%)	23	23	23	23

8 In CPS, about 40% of waste is directed to composting in 2070. In contrast, under the NZS, composting is reduced to 10% due to its relatively higher processing emissions, while the share of Bio-CNG and biomethanation increases from 2% and 5% in CPS to 20% and 17% in NZS respectively, promoting cleaner and more energy-efficient waste processing pathways.

Table 4.2: Targets for domestic wastewater

Strategies		Current Policy Scenario			Net Zero Scenario		
		2030	2050	2070	2030	2050	2070
Degree of utilisation (%)	Sewer Network	46	59	65	48	65	85
	Septic Tank	46	40	35	50	35	15
Treatment Technology (%)	Aerobic	64	64	64	64	42	26
	Anaerobic	36	36	36	36	58	74
Treatment Coverage (%)	Performance Improvement of Aerobic Wastewater Treatment Plants/ DeWATs	0	0	0	30	100	100
	Methane Recovery from Anaerobic Wastewater Treatment Plants/ DeWATs	10	10	10	30	100	100
	Faecal Sludge Treatment Plant	0	0	0	30	100	100
Biochemical Oxygen Demand (BOD) (gram/person/day)		41	41	41	41	41	41
Average Annual Per Capita Protein Consumption (kg/per person/year)		24.09	28.24	28.24	24.09	28.24	28.24

Table 4.3: Targets for industrial wastewater

Industries		Current Policy Scenario			Net Zero Scenario		
		2030	2050	2070	2030	2050	2070
Methane Correction Factor (MCF)	Textiles	0.8	0.8	0.8	0.8	0.8	0.8
	Paper and Pulp	0.1	0.1	0.1	0.1	0.1	0.1
	Fertiliser	0.3	0.3	0.3	0.1	0	0
	Sugar	0.8	0.8	0.8	0.8	0.8	0.8
	Petroleum	0.3	0.3	0.3	0.1	0	0
	Dairy[9]	0.5	0.5	0.5	0.8	0.8	0.8
	Meat	0.8	0.8	0.8	0.8	0.8	0.8
	Fish Processing	0.3	0.3	0.3	0.1	0	0

9 In the CPS scenario, a 0.5 MCF indicates that wastewater treatment in the dairy industry relies on a combination of technologies (Aerobic and Anaerobic) that are often overloaded and not well managed. In the Net Zero scenario, a higher 0.8 MCF is proposed, reflecting the adoption of anaerobic treatment and methane recovery technologies. This improvement will enhance treatment efficiency, reduce methane emissions, and enable the recovery of biogas for energy use, contributing to both environmental sustainability and long-term operational cost savings in dairy industry.

Industries		Current Policy Scenario			Net Zero Scenario		
		2030	2050	2070	2030	2050	2070
Methane Recovery (%)[10]	Textiles	70	70	70	90	100	100
	Paper and Pulp	70	70	70	90	100	100
	Fertiliser	0	0	0	0	0	0
	Sugar	70	70	70	90	100	100
	Petroleum	0	0	0	0	0	0
	Dairy	70	70	70	90	100	100
	Meat	70	70	70	90	100	100
	Fish Processing	0	0	0	0	0	0

While the common assumptions ensure methodological consistency, Current Policy Scenario and Net Zero Scenario differ in the extent and pace of technology deployment, treatment expansion and methane recovery. Under Current Policy Scenario, technological and treatment improvements occur gradually, reflecting current policy commitments and incremental changes. Methane recovery in domestic wastewater is limited at 10% and industry-specific recovery values remain constant across projection years; composting continues to form a substantial portion of solid waste processing and bio-methanation/bio-CNG scale more slowly.

The Net Zero Scenario is developed considering the goals, targets, and strategies defined in Table 4.4 across the three subsectors to achieve deep emissions reductions by 2070. These include stabilising per-capita waste generation, improving segregation, expanding treatment infrastructure, enhancing performance of Sewage Treatment Plants (STPs), adopting methane recovery technologies and transitioning industrial wastewater treatment systems.

Under Net Zero Scenario, more ambitious measures are adopted. These include universal methane recovery from anaerobic systems in domestic wastewater by 2050 and in industrial wastewater by 2040, a higher uptake of bio-CNG and bio-methanation, improved performance of aerobic sewage treatment plants, large-scale faecal sludge treatment and a stabilisation of per-capita waste generation by 2040. The Net Zero Scenario reflects a shift towards circularity and energy recovery across all subsectors.

10 Methane Recovery (%) is excluded for the Fertiliser, Petroleum, and Fish processing industries due to a lack of data.

Table 4.4: Sub-sectoral goals, targets, and strategies for the waste sector under the Net Zero Scenario

S. No.	Sub-sector	Resilience Goals	Targets	Strategies
1	Solid Waste Management	Transition towards a circular economy in the country	◆ Limit per capita waste generation to 0.622 (kg/capita/day) post 2040[11] ◆ 100% collection efficiency and source segregation by 2070 ◆ 85% waste processing by 2070[12]	◆ **Strategy 1**: Waste Reduction and Source Segregation ◆ **Strategy 2**: Strengthening the Primary and Secondary Collection and Transportation System ◆ **Strategy 3:** Processing and Resource Recovery ◆ **Strategy 4:** Scientific Disposal of Waste in Sanitary Landfills and Bioremediation
2	Domestic Wastewater	Promote integrated wastewater management systems that enhance treatment efficiency, methane recovery, and energy generation for a circular economy	◆ 85% augmentation of sewerage network by 2070 ◆ 100% treatment of collected wastewater post 2040 ◆ 74% of STPs/DeWATs will utilise anaerobic treatment systems by 2070	◆ **Strategy 1:** Universal access to scientific and economical toilets ◆ **Strategy 2:** Strengthening safe collection and transport of wastewater to suitable treatment facilities

11 Refer Annexure II– Part A for more details.

12 In Net Zero Scenario same targets are considered as in the Current Policy Scenario. The key difference is that in the Current Policy Scenario, wet waste processing is primarily focused on composting, whereas in the Net Zero Scenario, the emphasis shifts to cleaner solutions such as biomethanation and Bio-CNG, which not only manage waste more sustainably but also generate cleaner energy in the form of electricity and Bio-CNG.

S. No.	Sub-sector	Resilience Goals	Targets	Strategies
			• 100% performance improvement of aerobic wastewater treatment plants, methane recovery from anaerobic wastewater treatment plants/ DeWATs, and faecal sludge treatment by 2050	• **Strategy 3:** Maximise treatment and reuse of treated wastewater and faecal sludge by adopting efficient and scientific treatment technology with a suitable methane capture mechanism and use of alternative energy sources wherever feasible • **Strategy 4:** Enhance reuse, treatment, and safe disposal of wastewater. Reuse to be preferred wherever possible • **Strategy 5:** Public Awareness
3	Industrial Wastewater	Promote low-carbon industrial wastewater management through enhanced methane recovery and efficient treatment systems	• 100% methane recovery from industrial wastewater treatment by 2040 • 100% performance improvement of aerobic type industrial wastewater treatment plants by 2035	• **Strategy 1:** Implement Well-Managed Aerobic Systems (≈0 MCF) for Industrial Wastewater • **Strategy 2:** Enhance Methane Recovery from Industrial Wastewater

India can undertake climate actions based on these scenarios, to eventually embark on the Net Zero Pathway (see Figure 4.5).

Under the Current Policy Scenario, waste sector emissions are projected to rise steadily to 222.0 $MtCO_2e$ in 2050 and 266.0 $MtCO_2e$ in 2070. This increase reflects the growth in waste quantities and the limited methane recovery available under prevailing policies and technologies.

In comparison, under the Net Zero Scenario, waste sector emissions are projected to reach 10.9 $MtCO_2e$ by 2070, a decrease of 95.9% compared to the Current Policy Scenario projections. Of the total estimated reductions, the industrial wastewater sub-sector is projected to contribute the most, with a share of 49.4% (126.1 $MtCO_2e$), followed by domestic wastewater at 36.8% (93.9 $MtCO_2e$), and solid waste management at 13.8% (35.2 $MtCO_2e$). A detailed analysis of emissions reductions by sector is presented in Table 4.5 below.

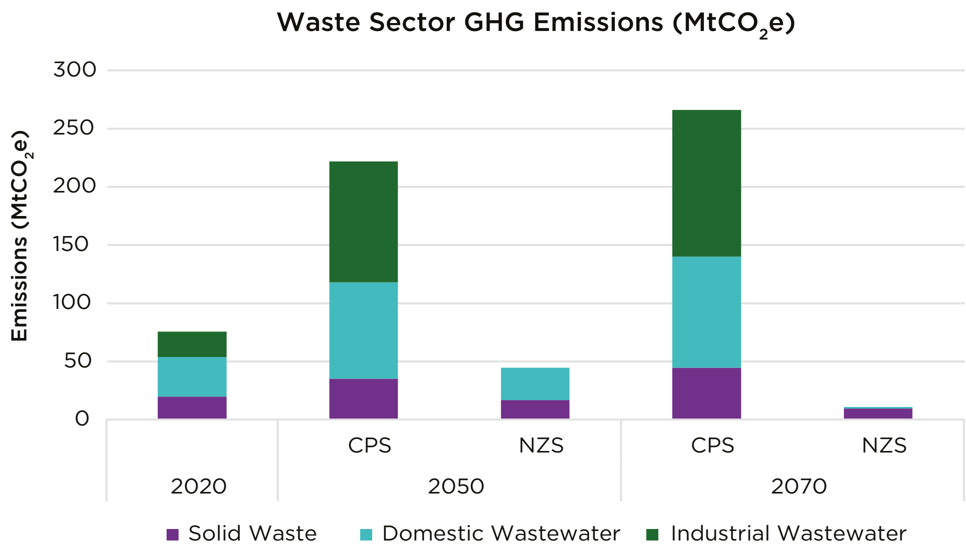

Figure 4.5: GHG emissions from waste sector in Current Policy Scenario (CPS) vs the Net Zero Scenario (NZS)

Emissions of 2020 are taken from BUR4 (based on IPCC Second Assessment Report (AR2)) and for projections emissions factors are based on the IPCC Fifth Assessment Report (AR5)

Table 4.5: GHG emissions reduction by waste sector under Net Zero Scenario

Sub-sector	2050	2070
Emissions ($MtCO_2e$) in Current Policy Scenario		
Solid Waste Management	35.1	44.6
Domestic Wastewater	83.0	95.4
Industrial Wastewater	103.9	126.1
Total	**222.0**	**266.0**
Emissions ($MtCO_2e$) in Net Zero Scenario		
Solid Waste Management (A)	16.7	9.5
Solid Waste Disposal	13.3	11.3
Biological treatment of solid waste (Composting/ Biomethanation/Bio-CNG)	7.8	3.5
Incineration/Waste-to-Energy	(4.4)	(5.3)
Domestic Wastewater (B)	27.9	1.4
Industrial Wastewater (C)	0.0	0.0
Total Remaining Emissions (A+B+C)	**44.6**	**10.9**
Emissions Reduction in Net Zero Scenario compared to Current Policy Scenario (%)		
Solid Waste Management	52.4%	78.8%
Domestic Wastewater	66.4%	98.5%
Industrial Wastewater	100%	100%
Total	**79.9%**	**95.9%**
Note: *( ) denotes negative value.*		

To move towards a Net Zero future, India will need to focus on continuously revising its Net Zero strategies to address residual/remaining emissions from the waste sector. Residual emissions are estimated to remain at 4.1% (10.9 $MtCO_2e$) under the Net Zero Scenario by 2070, compared to the Current Policy Scenario levels. Achieving a 100% reduction in waste sector GHG emissions would require India to adopt emerging technologies and develop additional mitigation strategies to close this gap by 2070.

It is crucial to acknowledge that the level of effort outlined in the Net Zero Scenario requires adaptation measures, substantial policy support, enabling frameworks, overcoming implementation barriers, capacity building, and financial support from city, state, and national governments, and the international community.

A key pillar of this transition is to identify and mobilise substantial financial resources. Implementing Net Zero strategies and adopting low-carbon development in the waste sector will require a clear roadmap for investment and funding. The total cost of achieving Net Zero emissions in this sector is expected to include significant capital for infrastructure development, operational improvements, and scaling up advanced technologies, such as waste-to-energy (bio-methanation), waste to bio-CNG plants, MRFs and composting technologies.

5

CHALLENGES

Challenges

5

The waste sector in India faces numerous challenges, particularly in managing waste streams and associated policy frameworks and data. These challenges differ significantly, reflecting disparities in infrastructure, awareness, and resource availability.

I. High Solid Waste Volumes

India continues to face growing pressure from the increasing volume and complexity of solid waste generated. Rapid urbanisation and population growth have intensified waste generation, while the availability of land for sanitary landfill development has steadily decreased. Existing landfills are heavily overburdened, and constrained by high land costs and competing land-use demands. As cities expand further, the challenge of safely managing rising waste volumes is becoming increasingly complex, straining municipal systems and elevating environmental risks.

II. Limited Solid Waste Segregation

Limited segregation at source remains one of the most significant barriers to effective waste management. This hampers downstream processing, contaminates recyclable fractions, lowers material recovery rates, and reduces the overall value of recyclables. Also, the adoption of low-carbon technologies for waste processing usually requires pure-source feedstocks; this is especially critical for processing organic waste.

III. Challenges in Solid Waste Collection, Transportation, and Handling

Infrastructure gaps hinder the implementation of comprehensive solid waste management systems. Many cities still lack efficient and reliable systems for waste collection, handling, and transportation. Collection coverage remains uneven in many areas, especially in dense informal settlements, peri-urban fringes, and hilly terrain. Additionally, many cities lack well-designed transfer stations, so waste is often transported through temporary or open dumping sites. Manual handling remains high, increasing occupational risks and decreasing efficiency.

In terms of transportation, vehicles used for both collection and transportation are often poorly maintained, leading to breakdowns, leachate leaks, and higher operating costs. The lack of dedicated vehicles for segregated streams leads to recombination of waste during collection. At the same time, the lack of route optimisation and tracking causes inefficient crew deployment, increased fuel consumption, and avoidable GHG emissions.

IV. Low Processing and Scientific Disposal of Solid Waste

With only about 39% of waste being scientifically processed, most urban areas rely on open dumping or underperforming treatment facilities. These gaps in treatment capacity have led to higher GHG emissions from the solid waste sub-sector. Although the informal sector plays a vital role in recycling, its contributions remain largely unrecognised and poorly integrated into formal systems.

V. Unmanaged Plastic Waste

Plastic waste adds another layer of complexity, with improper disposal contributing to river and marine pollution, and the dispersal of microplastics adversely affects human and ecological health. Public awareness and behavioural adoption of segregation and recycling remain limited, further constraining progress towards a circular economy.

VI. Rural Waste Management Challenges

Rural areas face structural limitations in waste management due to the absence of basic infrastructure. Most rural areas are yet to develop systems for organised waste collection, source segregation, and transportation to disposal sites, resulting in unregulated dumping. Financial constraints, low technical capacity, and limited awareness of sustainable waste practices further hinder responsible management.

VII. Inadequate Wastewater Collection and Conveyance

Limited and ageing sewer networks make wastewater management challenging. Centralised sewer systems remain expensive to build and maintain. Informal settlements, expanding due to unplanned urbanisation, often lack sewer connections or septic tanks. As a result, untreated wastewater frequently gets dumped into drains, rivers, and groundwater. In rural areas, the absence of drainage and conveyance systems leads to wastewater stagnation and contamination of local water sources.

VIII. Insufficient Wastewater and Faecal Sludge Treatment Capacity and Performance

Existing treatment infrastructure has not kept pace with rising wastewater volumes. Many treatment plants are overburdened, under-performing, or non-functional due to poor design, inadequate operation, and lack of maintenance. Limited faecal sludge treatment plants and weak co-treatment mechanisms compound the issue. The shortage of trained personnel for operating treatment systems further undermines performance.

IX. Behavioural and Social Barriers in Wastewater Management

Social, cultural, and behavioural barriers often hinder the adoption of improved sanitation and wastewater systems. In regions facing water scarcity, pour-flush toilets become impractical, reducing the feasibility of safe containment systems. Cultural barriers and social stigma around waste handling reduce community uptake of sustainable domestic wastewater management solutions.

X. Industrial Wastewater Standards and Pollutants

Ineffective treatment systems with high Methane Correction Factors (MCFs) lead to increased methane emissions, hindering industrial wastewater management. In addition, weak monitoring techniques and gaps in sector-specific BOD/COD regulations often hinder efforts to reduce eutrophication. The absence of widespread methane recovery mechanisms across industrial treatment facilities results in missed opportunities for energy capture and reducing overall emissions.

XI. Policy Implementation Gaps

India has made significant progress in developing policies for waste and wastewater management; however, institutional capacity, funding, and enforcement at the local level are still being strengthened.

XII. Fragmented Data Systems and Poor Data Quality

A robust data ecosystem is crucial for effective planning; however, the current data remains scattered across various agencies, including CPCB, MoHUA, NEERI, NITI Aayog, and various central and state departments, each employing different methodologies and reporting frameworks. The absence of extensive historical datasets, combined with limited long-term policy planning, limits guidance for effective long-term planning and analysis.

XIII. Lack of Disaggregated and Region-Specific Data for Domestic Wastewater

Limited data on indicators such as per capita waste generation, protein intake, disposal methods, waste infrastructure, and biological treatment techniques remain a major challenge. This gap reduces the accuracy of treatment estimates. Without region-specific information on waste composition and treatment practices, national averages are used, which might not accurately reflect local circumstances.

XIV. Weak Future Projection Models

Current projections of waste generation and treatment capacity rely heavily on extrapolated trends and static parameters (e.g., fixed BOD values and methane recovery rates). These models do not adequately incorporate anticipated changes in technology performance, industrial efficiency, population growth, or climatic conditions.

XV. Financing Constraints in Waste Management

Financing remains a significant barrier to scaling waste management systems across India. Urban Local Bodies (ULBs) often lack the financial resources to invest in waste infrastructure, while existing grants are insufficient to meet long-term capital and O&M needs. Access to climate finance, private investment, and innovative funding mechanisms is limited, slowing the adoption of modern technologies and circular economy measures.

6

SUGGESTIONS

Suggestions

6

India's commitment to Net Zero emissions by 2070 involves eliminating waste sector emissions through low-carbon waste management systems, cutting-edge technologies, and innovative policies. Key strategies to enable the waste sector's contribution to Net Zero are listed below:

A. Solid Waste Management

1. Waste Reduction and Source Segregation

i. Achieve the Swachh Bharat Mission (SBM) 2.0 target of 100% source segregation through community engagement using social media campaigns, workshops, and local outreach activities.

ii. Limit per capita waste generation to 0.622 kg/capita/day post 2040, in line with developed nation standards and United Nations Environmental Programme (UNEP) circular economy benchmarks.

iii. Reduce waste at source by operationalising Extented Producer Responsibility (EPR), tax incentives, eco-labelling, and development of eco-industrial parks focused on recycling industries (CPHEEO, 2016).

2. Strengthening Primary and Secondary Collection and Transportation

i. Improve collection efficiency to 100% door-to-door waste collection, supported by waste quantification surveys to identify leakages in line with SBM 2.0 guidelines.

ii. Strengthen primary collection by identifying the required workforce and vehicle capacities and deploying compartmentalised vehicles for segregated waste streams

iii. Integrate technologies such as GPS-based route optimisation, digital tracking to monitor bin filling, and RFID-enabled vehicles to enhance operational efficiency.

iv. Enhance secondary waste collection by upgrading transfer stations or storage depots, especially where treatment and disposal sites are more than 15 miles from the city.

v. Design transfer stations to minimise waste handling and, in cities with low segregation levels, incorporate pre-sorting lines or decentralised Material Recovery Facility (MRF) within these facilities.

vi. Strengthen plastic waste management by improving the collection of low-value plastics, expanding recycling facilities, and preventing leakages through monitoring.

3. Processing and Resource Recovery

i. Align processing technology choices with region specific waste composition and ensure adherence to standard norms to maintain efficiency, sustainability, and scalability.

ii. Increasing biodegradable waste processing capacity by adopting bio-methanation and composting, and prioritising bio-methanation in cities with high source segregation; use feasibility assessments to determine centralised or decentralised approach for the system. Support future Waste-to-Energy (WtE) initiatives, such as waste-to-green hydrogen.

iii. Enhance waste processing to achieve 85% treatment of Muncipal Solid Waste (MSW) using a combination of technologies, including Bio-CNG (20%), bio-methanation (17%), composting (10%) for organic waste, WtE (15%) for non-recyclable dry and mixed waste, and Material Recovery Facility (MRF) for recyclables. Ensure only inert and process rejects fractions are sent to sanitary landfills.

iv. Integrate informal waste sector workers into formal Solid Waste Management (SWM) systems through dedicated policies, capacity building initiatives, and partnerships at MRFs and recycling facilities

v. Establish dedicated waste management zones in master plans to streamline waste collection and processing operations and prevent ad-hoc or unplanned dumping.

4. Scientific Disposal and Bio-remediation

i. Develop sanitary landfill sites for the safe disposal of rejects from processing facilities and inert waste. In rural areas, adopt a cluster-based approach to enable multiple villages to share a single sanitary landfill.

ii. Equip sanitary landfills with Landfill Gas (LFG) capture systems to reduce emissions from organic rejects and improve environmental performance.

iii. Ensure remediation of legacy waste in accordance with SBM 2.0 guidelines, for cities with populations under one million.

iv. Ensure SWM facilities are resilient to climate risks such as floods, heat waves, and extreme rainfall, which often affect operations.

B. Domestic Wastewater

1. Universal access to scientific and economical toilets

i. Align treatment and discharge pathways based on local geography, recognising that India's diverse landscapes require customised systems.

ii. Address operational challenges observed in many constructed toilets under SBM, by improving septic tank cleaning services, ensuring adequate water availability for regular use, and supporting households in undertaking repair and maintenance.

iii. Implement a two-pronged approach to achieve universal access and sustained functionality:

- **Construction:** identify households without individual toilets and support the construction of scientifically designed, location-appropriate toilets, particularly in areas where households rely on community toilets.
- **Retrofitting:** upgrade unscientific systems by addressing design issues such as septic tanks without soak pits, improperly spaced twin pits, missing Y-junctions, faulty pipes or chambers, and direct discharge into open drains. Connect households to sewer networks where feasible to ensure safe containment and reduce pollution risks.

2. Safe collection and transfer to treatment facilities

i. Achieve 85% sewer network coverage by expanding centralised sewer systems wherever technically feasible, while recognising that India's diverse geography, such as hilly terrain, sandy coastal soils, and low-density settlements, renders sewer construction difficult or impractical in some areas.

ii. Adopt suitable alternatives where centralised systems are not viable, such as well-designed on-site sanitation systems with scheduled desludging services or decentralised sewerage systems for small habitations.

iii. Implement interception and diversion (I&D) systems in locations where wastewater discharges into open drains, redirecting them to suitable treatment facilities.

iv. Ensure that States and Local Bodies plan sewer expansion, on-site system upgrades, and decentralised networks in a phased manner, aligning with local needs, topographical constraints, and wastewater generation trends.

3. Maximising treatment and faecal sludge treatment with methane recovery

i. Achieve 100% treatment of collected wastewater by 2050 while strengthening the operation and maintenance of existing and upcoming aerobic Sewage Treatment Plants (STPs) to ensure they function efficiently, maintain adequate treatment volumes.

ii. Prioritise the adoption of anaerobic treatment systems with integrated methane recovery infrastructure while expanding Sewage Treatment Plants (STP)/ Decentralised Wastewater and Treatment System (DeWATs) capacity, to enable methane utilisation for energy generation and support long-term emission reduction objectives. Ensure that approximately 74% of sewage treatment capacity is anaerobic, with 100% methane recovery by 2070.

iii. Target the remaining 26% of collected wastewater for treatment through aerobic systems, ensuring efficient operations to achieve zero emissions during treatment.

iv. Prioritise faecal sludge management and treatment in areas dependent on on-site sanitation systems, by establishing faecal sludge treatment plants (FSTPs) and expanding co-treatment arrangements at nearby STPs. States should identify suitable locations for establishing FSTPs and co-treatment facilities to ensure 100% faecal sludge treatment by 2070.

4. Enhancing circularity through reuse and recycling

i. Promote reuse of treated wastewater for tertiary purposes like agriculture, construction, and horticulture to decrease freshwater demand and promote water conservation, especially in water-stressed regions across India.

ii. Address rural wastewater challenges by constructing covered drainage systems to reduce disposal into low-lying areas and improve sanitation outcomes.

C. Industrial Wastewater

1. Implement well-managed aerobic systems (≈0 MCF)

i. Promote well-managed aerobic treatment systems to achieve a near-zero Methane Correction Factor (≈0 MCF) by preventing the formation of anaerobic conditions in industries using aerobic treatment technologies, such as fertilisers, petroleum, and fish processing.

2. Enhance methane recovery from industrial wastewater

i. Achieve 100% methane recovery by 2040 from industries using anaerobic treatment technologies to support emission reduction and meet energy needs sustainably.

ii. Upgrade existing wastewater treatment infrastructure and adopt advanced methane recovery systems to improve overall performance.

iii. Support industries in reducing GHG emissions by maximising the recovery and reuse of treatment by-products, such as utilising biogas produced from anaerobic digestion, reusing treated wastewater, and reclaiming usable materials from the treatment process.

D. Policy Framework

1. Strengthening Technical Expertise and Capacity Building

i. Strengthen technical capabilities of government officials and sector stakeholders to fast-track waste management strategies, supported by training programmes.

ii. Ensure that training programmes cover data collection protocols, digital reporting tools, waste categorisation techniques, and Quality Assurance/ Quality Control (QA/ QC) processes that strengthen the accuracy of reported values.

iii. Ensure long-term capacity-building investments to enable the adoption of innovative approaches and improve overall institutional readiness.

2. Advancing Climate-based Participatory Budgeting and Sustainable Procurement

i. Introduce climate-based participatory budgeting to enable communities to engage directly in sustainable waste management projects.

ii. Promote sustainable procurement practices across public sector projects.

iii. Strengthen public ownership of projects through the involvement of local communities in decision-making processes.

3. Enabling Private Sector Involvement

i. Encourage private investment in waste processing and recycling technologies, sustainable packaging, and circular economy models.

ii. Scale up initiatives such as the SATAT scheme and GOBARdhan through increased private sector participation.

iii. Promote eco-friendly products and sustainable business practices to strengthen sustainable procurement and support the transition to a greener economy.

4. Strengthening Public Awareness and Engagement

i. Ensure active public participation through social media campaigns, government platforms such as MyGov.in workshops, and educational programmes.

ii. Incorporate Mission LiFE into behavioural change initiatives to promote sustainable practices such as waste segregation, mindful consumption, and eco-friendly behaviour.

5. Establishing a Robust Monitoring and Evaluation Framework

i. Establish a clear framework for monitoring and evaluating mitigation efforts for the waste sector.

ii. Ensure application of effective monitoring methodologies that track expenditures and measure climate and infrastructure service outcomes.

iii. Strengthen inter-agency and inter-departmental coordination to align waste-related regulations, targets, and reporting requirements.

E. Strengthen Data Ecosystem

i. Establish a unified national waste data framework that integrates datasets from CPCB, MoHUA, NITI Aayog, NEERI, and State Pollution Control Boards, using standardised methodologies, timelines, and reporting formats, supported by a centralised digital platform for real-time data collection. Integrate data transparency and public disclosure mechanisms to enhance accountability and enable third-party validation.

ii. Deploy remote sensing, IoT-based sensors, and automated monitoring systems for continuous measurement of waste quantities, landfill emissions, leachate generation, Sewage Treatment Plants (STP)/ Decentralised Wastewater and Treatment System (DeWATs) performance, and industrial effluent trends.

iii. Mandate the tracking and reporting of disaggregated datasets on key indicators such as per capita waste/wastewater generation, disposal methods, wastewater discharge pathways and processing, etc., to improve planning accuracy.

iv. Conduct periodic region-specific waste and wastewater characterisation analysis to enable understanding of local conditions and improve technology selection and planning.

v. Improve industrial waste data reporting by mandating annual, industry-specific reports on wastewater generation, treatment technologies, Biological Oxygen Demand (BOD) & Chemical Oxygen Demand (COD) loads, etc.

vi. Promote collaboration between research institutions, civil society organisations, and government agencies to co-develop analytical models and improve long-term projection models and strategic planning.

ANNEXURES

Annexure I: Quality Control and Quality Assurance for Emission Estimation

Part A: Sectoral Quality Control (QC) and Quality Assurance (QA)

Internal quality control (QC) procedures applied to the emission estimates include generic quality checks in terms of the calculations, processing, consistency, and clear recording and documentation as follows:

- **Activity Data Selection:** National-level datasets have been used to ensure relevance across time and geography with consistent time-series data across all sub-sectors.
- **Calculation Verification:** Spreadsheets have been reviewed to confirm the correct application of formulas, activity data, and emission factors, ensuring error-free computations.
- **Unit and Measurement Consistency:** Parameters and emissions have been cross-checked for accurate recording, proper and consistent unit conversions and measurement throughout the reporting period.
- **Trend Analysis:** Emission estimates have been analysed for consistency in national-level trends over the assessment period. Major deviations were identified and addressed when not attributable to changes in activity data or emission factors.
- **Transparent Documentation:** All equations, input data, intermediate formulae, and outputs have been clearly documented within spreadsheets for each sub-category.
- **Citation Compliance:** All references to activity data and emission factors have been cited in line with citation policies to ensure full traceability.
- **Data Gap Reporting:** Included and excluded categories, along with the rationale for assumptions used to address data gaps, have been transparently reported (Annexure II).

Part B: Specific QC/QA Procedures for Key Waste Sector Categories

A. Solid Waste Disposal

- The First Order Decay (FOD) model has been utilised to estimate emissions, incorporating historical solid waste disposal data from 1955 onward.
- Historical data gaps in waste generation and composition have been addressed by interpolating national datasets, ensuring alignment with the 2006 IPCC guidelines.
- Per capita waste generation rates have been projected using growth trends from datasets such as the India Energy Security Scenario (IESS), the Municipal Solid Waste Management Manual 2016, and NEERI studies.
- The national per capita MSW generation rate used in the estimates has been validated against the IPCC default value of 0.12 tonnes/capita/year, confirming they fall within the uncertainty range. Future MSW generation projections rely on average national growth in per capita waste generation.
- Improvements in waste management technologies, such as increased biological treatment and material recovery, are expected to significantly reduce the volume of waste sent to disposal sites/landfills by 2070.

B. Biological Treatment of Waste

Biological treatment methods such as composting and anaerobic digestion (bio-methanation), have been assessed at the national level for municipal solid waste. Key considerations include:

- National-level estimates of biologically treated waste, with data gaps addressed through interpolation for missing years.
- Incremental increases have been assumed in composting and bio-methanation capacity, based on historical growth trends, technological advancements, and ongoing government initiatives and policies.
- The lack of disaggregated data on waste fractions and treatment efficiency, particularly at regional levels, has contributed to variability in estimates. Uniform waste composition data and treatment efficiencies have been applied across the projection period.

C. Domestic Wastewater Treatment and Discharge

- Population projections from NITI Aayog have been used to estimate wastewater generation.

- The degree of utilisation for treatment systems, such as sewers, septic tanks, and latrines, has been derived from historical datasets and projected incrementally to 2070.
- Per capita BOD values have been assumed constant over the projection period, based on BUR, NATCOM-III and IPCC guidelines.
- It is assumed that all wastewater collected via sewer systems will be treated, eliminating untreated discharges. It is also assumed that improvements in treatment infrastructure will reduce emissions over time.
- Wastewater treatment capacity is projected to increase in line with the current policies and targets, with systems designed to prevent untreated discharge.

D. Industrial Wastewater Treatment and Discharge

- Emission estimates for industrial wastewater have been based on a tier-1 approach, covering eight industrial sectors using national averages for production and wastewater generation.
- Default values for treatment system efficiencies and methane recovery rates have been sourced from NATCOM-III and BUR-III & IV and NEERI studies' national datasets.
- Methane recovery is assumed to improve over time, particularly in energy-intensive industries, contributing to lower overall emissions. However, it is assumed to remain constant under the Current Policy Scenario estimates.
- Limited availability of production and wastewater treatment data has introduced variability. Static assumptions for wastewater generation per unit product and treatment efficiencies may not fully reflect on-ground changes in industrial processes over time.

Annexure II: Data Sources and Assumptions

Part A: Data Sources and Assumptions for Solid Waste Management

Activity Data/ Emission Factor	Methodological Approach	Data Source
Activity Data		
Population (P)	◆ As reported for the census years 1991, 2001 and 2011. ◆ Population projections for selected years between 2020 and 2070 have been sourced from NITI's dataset. For the remaining years, population estimates have been derived based on decadal growth trends in the shared dataset..	◆ Census of India ◆ NITI Aayog, Government of India
Mass of Waste deposited (W)	**a. Per Capita Waste Generation:** ◆ Municipal Solid Waste (MSW) generation for the period 2030 to 2070 has been estimated based on population projections and the per capita waste generation rates sourced from IESS, the open-source tool developed by NITI Aayog. ◆ For intermediate years per capita waste generation has been calculated based on the 1.3% annual growth rate specified in the SBM's MSW Management Manual 2016. ◆ The Net Zero Scenario assumes per capita waste generation at 0.622 kg/ capita/day post 2040, aligning with developed nation standards and global per capita waste generation under circular economy scenario, reported by the United Nations Environment Programme (UNEP, 2024).	◆ India Energy Security Scenario (IESS, NITI Aayog) ◆ Municipal Solid Waste Management Manual (2016), Part II, Swachh Bharat Mission, Ministry of Urban Development, Government of India (CPHEEO, 2016)

Activity Data/ Emission Factor	Methodological Approach	Data Source
	b. Proportion of waste to disposal site and waste processing: • Data on waste sent to landfills and for waste processing (biological treatment and waste incineration waste) is available for the years 2005, 2020, 2021 and 2022. • For landfill projections, the annual average growth (2014 to 2021) was later applied to project landfill volumes until 2070 under the Current Policy Scenario. • Based on historical trends, current policy parameters and benchmarks in developed nations, it is projected that by 2070, 15% of the waste generated will be sent to landfills. Technological advancements are expected to significantly reduce waste rejects, leading to efficient treatment of the remaining 85%. • Projections for processing methods like composting, bio-methanation, incineration, and MRF were based on their 2020 baseline shares. • Annual projections incorporate incremental improvements in technologies like bio-methanation, composting, waste incineration/RDF, and MRF.	• NEERI • Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) rules 2000, CPCB, 2014-15 (CPCB, 2015) • Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) rules 2016, CPCB, 2015-16 (CPCB, 2015) • Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) rules 2016, CPCB, 2016-17 (CPCB, 2017) • Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) rules 2016, CPCB, 2017-18 (CPCB, 2018) • Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) rules 2016, CPCB, 2018-19 (CPCB, 2019) • Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) rules 2016, CPCB, 2019-20 (CPCB, 2020) • Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) rules 2016, CPCB, 2020-21 (CPCB, 2021)

<table>
<tr><th>Activity Data/ Emission Factor</th><th>Methodological Approach</th><th>Data Source</th></tr>
<tr><td colspan="3">Emission Factors</td></tr>
<tr><td>Degradable Organic Carbon (DOC)</td><td>

DOC values for the organic fraction of waste has been calculated using IPCC default values for degradable components (paper, rags, compostable matter) along with reported waste composition data across different time periods.
Waste composition data for the years 1971, 1995, 2005 and 2020 is assumed to be applicable for the periods of 1954-1994, 1995-2004, 2005-2018, 2019-2070 respectively.

Default DOC content values as per 2006 IPCC Guidelines:
<table>
<tr><th>Component</th><th>Default DOC Content values (Wet waste)</th></tr>
<tr><td>Paper</td><td>40%</td></tr>
<tr><td>Rags</td><td>24%</td></tr>
<tr><td>Compostable Matter</td><td>15%</td></tr>
<tr><td colspan="2">Source: IPCC 2006</td></tr>
</table>
</td><td>
Default DOC content:

2006 IPCC Guidelines for National GHG Inventories, Vol. 5, Chapter 2: Waste Generation, Composition and Management Data, Table 2.5 (Intergovernmental Panel on Climate Change [IPCC], 2006)

Waste composition from 1971 to 2020:

Integrated Modelling of Solid Waste in India (1999), CREED Working Paper Series no 26 and CPCB, 1999
CPCB and NEERI (2005), Table 2, pg. 3 (CPCB, 2005)
CPHEEO Manual on Municipal Solid Waste Management-2016, Table 1.6 (CPHEEO, 2016)
Toolkit Preparing City Solid Waste Action Plan under SBM 2.0 Managing Biodegradable Waste, 2022 Centre for Science and Environment (CSE, 2022)

</td></tr>
<tr><td>Decomposable Fraction of DOC (DOC_f)</td><td>0.5</td><td>IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Equation 3.7 (IPCC, 2006)</td></tr>
<tr><td>Methane Correction Factor (MCF)</td><td>

MCF for unmanaged shallow landfill with depth less than five metrer (0.4) has been used in the Current Policy Scenario estimates
Under Net Zero Scenario MCF of managed landfill (1.0) has been used

</td><td>IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.1 (IPCC, 2006)</td></tr>
<tr><td>Fraction of CH_4 in generated landfill gas (F)</td><td>0.5</td><td>IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Page 3.15 (IPCC, 2006)</td></tr>
<tr><td>Oxidation factor (OX)</td><td>0</td><td>IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.2 (IPCC, 2006)</td></tr>
</table>

<table>
<tr><th>Activity Data/ Emission Factor</th><th>Methodological Approach</th><th>Data Source</th></tr>
<tr><td>Methane Recovery (R)</td><td>0</td><td>IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Section 3.2.3 (IPCC, 2006)</td></tr>
<tr><td>Reaction Constant (k)</td><td>0.84</td><td>IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.3 (IPCC, 2006)</td></tr>
<tr><td>IPCC default Emission Factors for CH_4 and N_2O emissions from biological treatment of waste</td><td>
<table>
<tr><th rowspan="2">Type of Treatment</th><th colspan="2">CH_4 Emission Factors (kg CH_4/ tonne waste treated)</th><th colspan="2">N_2O Emission Factors (kg N_2O/ tonne waste treated)</th></tr>
<tr><th>Dry weight basis</th><th>Wet weight basis</th><th>Dry weight basis</th><th>Wet weight basis</th></tr>
<tr><td>Compost-ing</td><td>10</td><td>4</td><td>0.6</td><td>0.24</td></tr>
<tr><td>Anaerobic digestion at biogas facilities (bio-meth-anation)</td><td>2</td><td>0.8</td><td colspan="2">Negligible</td></tr>
</table>
</td><td>IPCC 2006 Guidelines, Vol. 5. Chapter 4: Biological Treatment of Waste, Table 4.1 (IPCC, 2006)</td></tr>
</table>

Part B: Data Sources and Assumptions for Domestic Wastewater Treatment and Discharge

<table>
<tr><th>Activity Data/ Emission Factor</th><th>Methodological Approach</th><th>Data Source</th></tr>
<tr><td colspan="3">Activity data</td></tr>
<tr><td>Population (P)</td><td>
As reported for the census years 1991, 2001 and 2011.
Population projections for select years between 2020 and 2070 has been sourced from NITI Aayog. Year-wise estimates for the remaining years has been derived from decadal growth trends from the dataset.
</td><td>
Census of India
NITI Aayog, Government of India
</td></tr>
</table>

Activity Data/ Emission Factor	Methodological Approach	Data Source
Per capita BOD in inventory year (g/ person/day)	◆ Per capita BOD value (i.e. 41 g/ person/day) is assumed to be constant from 2030 to 2070.	◆ India Third National Communication (NATCOM-III) and Initial Adaptation Communication, MoEFCC, GoI, 2023 (MoEFCC, 2023)
Degree of utilisation of treatment/ discharge pathway or system, j, for each income group fraction i (Ti, j)	**a. Degree of Utilisation:** ◆ Treatment and discharge pathways are classified under the 2006 IPCC Guidelines as septic tank, sewer, latrine, others, and None (IPCC, 2006) ◆ The degree of utilisation of treatment/discharge pathway or system is based on the latrine facility dataset sourced from the Census of India (2001 and 2011), National Sample Survey (76th and 79th) Round (2018 and 2022-23), and National Family Health Survey (NFHS) (2005-06, 2014-15 and 2019-21) ◆ Projections until 2070 were made using an annual average increase methodology based on historical trends from 2001 to 2022. By calculating the average annual increase required to achieve the target sewer network coverage, the share was incrementally adjusted each year. **b. Sewage Treatment Plants (STP) Status:** ◆ STP capacity data is available for the years 2008-09, 2014-15, and 2020. ◆ The degree of utilisation of treatment systems is estimated for 2005 to 2010, 2016 to 2018, 2021, and 2022. ◆ Methane emissions from domestic wastewater treatment are estimated at 10%, based on NEERI data sets, and are assumed to remain constant under the Current Policy Scenario through 2070.	**Latrine Facility Datasets:** ◆ 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, table 6.5 (IPCC, 2006) ◆ Census of India – Availability and type of latrine facility: 2001 – 2011 ◆ Drinking Water, Sanitation, Hygiene, and Housing Condition, NSS 76th Round (2018), Page 33 (MoSPI, 2018) ◆ Comprehensive Annual Modular Survey, NSS 79th Round (2022-2023) (MoSPI, 2023). ◆ Availability of Toilets at the Household Level in India: Evidence from NFHS (NirmalKumar & Sivasankar, 2024) **Status of Sewage Treatment Plant (STP) data** ***2008-09:*** ◆ CPCB (2008): Evaluation of Operation and Maintenance of Sewage Treatment Plants in India-2007. Information referred from Table 2.1, Table 2.2 and Chapter 3 (CPCB, 2008) ◆ CPCB (2009): Status of Water Supply, Wastewater Generation and Treatment in Class-I Cities & Class-II Towns of India. Information referred from Table 3.4, Table 3.5, Table 3.6, Table 3.11, Table 3.12, Table 3.18, Table 3.19 (CPCB, 2009)

Activity Data/ Emission Factor	Methodological Approach	Data Source
	(i) Piped sewer: ◆ Operational STP capacity is identified from CPCB's STP performance evaluation reports. ◆ STPs are categorised as aerobic and anaerobic based on treatment technology used. ◆ Installed but non-operational STPs are considered 'collected and not treated'. ◆ Percentages from these three values are estimated from 2005-2022 and the corresponding percentage multiplied with 'piped sewer' data to estimate emissions from each discharge pathway. ***(ii) Projection: Sewage Treatment Plants (STP) Status (2023-2070)*** ◆ A decremental approach has been used to project the percentage of sewers with collected and untreated waste from 2023 to 2070, aiming for 0% untreated sewage by 2070. ◆ Historical data from 2008-2009 and 2014-15 has been analysed to calculate the average annual reduction in untreated sewage. This linear decremental rate was applied year by year, ensuring steady progress. ◆ The technology split between aerobic and anaerobic systems, as in the baseline year, is assumed to be constant over the projection period due to historical variability.	◆ CPCB (2010): Annual report 2009-10. Information referred from Table 6.2, Table 6.3 ◆ CPCB (2013): Performance Evaluation of STPs under NCRD. Information referred from Table 2, Table 3, Table 4, Table 5, Table 8, Table 14, Annexure – IV ***2014-15:*** ◆ CPCB (2015): Inventorization of STPs. Information referred from Table 3 and Chapter 4 ◆ CPCB: Monitoring of STPs in Karnataka 2014-15. Information referred on STPs throughout the document ***2020:*** ◆ National Inventory of Sewage Treatment Plants, March 2021, CPCB
Fraction of population in income group i (Ui)	The values of the fractions of population in income groups is available from 2005 to 2070.	***2005-2010:*** Population Projections for India and States 1996-2016 (Registrar General, India–Ministry of Home Affairs); Table 10–Page no. 71–Total Population, Table 16–Page no. 89–Urban Population

<table>
<tr><th>Activity Data/ Emission Factor</th><th>Methodological Approach</th><th>Data Source</th></tr>
<tr><td></td><td></td><td>2011-2019:
Population Projections for India & States 2011-2036 (Table no. 8, 9 and 10), Ministry of Health & Family Welfare, (Downloaded from Census of India official website)
2020-2070:
NITI Aayog, Government of India.</td></tr>
<tr><td>Organic Component removed as Sludge, kg BOD/ year (BOD)</td><td>0</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.1 (IPCC, 2006)</td></tr>
<tr><td>Correction factor for additional industrial BOD discharged into sewers (I)</td><td>Based on the 2006 IPCC Guidelines, the default values of “I”, for collected and uncollected wastewater, have been used, for assessment.<table><tr><th>“I” for Collected Wastewater</th><th>“I” for Uncollected Wastewater</th></tr><tr><td>1.25</td><td>1</td></tr></table></td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6–Wastewater treatment and discharge, Equation 6.3 (IPCC, 2006)</td></tr>
<tr><td>Amount of CH_4 recovered in inventory year (R)</td><td>0</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, equation 6.1 (IPCC, 2006)</td></tr>
<tr><td>Annual per capita protein consumption, kg/ person/year</td><td>◆ Per capita protein consumption values are sourced from the NSSO report on nutritional intake in India, 2011-12.
◆ As updated year-wise values are unavailable, the 2011-12 figures have been applied for the baseline year 2020.
◆ Post 2047, the per capita protein (28.24 kg/person/year) consumption is projected to meet the suggested levels outlined in the Dietary Guidelines for Indians 2024 (ICMR-National Institution of Nutrition), assuming India achieves the required protein intake by that year. This value is assumed to be constant until 2070.</td><td>2011-12:
◆ Nutritional Intake in India 2011-12. The NSSO survey was conducted over two rounds (or schedules). Values used are average values based on findings across the two schedules in the NSSO survey 2011-12 as indicated in Table 3A & Table 3B (MoSPI, 2014)
2019-21:
◆ National Family Health Survey (NFHS-5), 2019-2021 (Ministry of Health and Family Welfare, 2021)</td></tr>
</table>

<table>
<tr><th>Activity Data/ Emission Factor</th><th>Methodological Approach</th><th>Data Source</th></tr>
<tr><td></td><td>◆ The weighted average of protein intake value is calculated using the proportion of vegetarian and non-vegetarian population as per the NFHS-5 Report, 2019-2021.
◆ Per capita protein consumption between 2020 and 2047 has been estimated using the CAGR.</td><td>2024:
◆ Dietary guidelines by Indian Medical Council Research (ICMR), 2024</td></tr>
<tr><td colspan="3">Emission factors</td></tr>
<tr><td>Maximum CH_4 producing capacity, kg CH_4/ kg BOD (Bo)</td><td>0.6</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6–Wastewater treatment and discharge, Table 6.2 (IPCC, 2006)</td></tr>
<tr><td>Methane correction factor (MCF_j)</td><td>The following assumptions have been made:
◆ Untreated wastewater collected via sewers may remain in ‘stagnant sewers’ or be ‘discharged into aquatic environments. As the quantity discharged to water bodies is unknown, the entire volume of untreated wastewater is accounted for under ‘discharge to aquatic environments.
◆ Under the Current Policy Scenario, untreated sewage (collected but not treated) is projected to reach 0% by 2040 in India. This phased reduction is expected to eliminate emissions from untreated sewage.</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater treatment and discharge, Table 6.3 (IPCC, 2006)</td></tr>
<tr><td></td><td>
<table>
<tr><th>Treatment/ discharge pathway or system (j)</th><th>MCF_j</th></tr>
<tr><td>Anaerobic reactor</td><td>0.80</td></tr>
<tr><td>Centralised, aerobic treatment plant not well managed, overloaded</td><td>0.30</td></tr>
<tr><td>Centralised, aerobic treatment plant well managed</td><td>0.00</td></tr>
<tr><td>Stagnant Sewer</td><td>0.50</td></tr>
<tr><td>Sea, lake, or river discharge</td><td>0.10</td></tr>
<tr><td>Flowing Sewer (open/ closed)</td><td>0.00</td></tr>
<tr><td>Septic system</td><td>0.50</td></tr>
</table>
</td><td></td></tr>
</table>

<table>
<tr><th>Activity Data/ Emission Factor</th><th>Methodological Approach</th><th>Data Source</th></tr>
<tr><td></td><td>
<table>
<tr><th>Treatment/ discharge pathway or system (j)</th><th>MCF_j</th></tr>
<tr><td>Latrine–Dry climate, groundwater table lower than latrine, communal (many users)</td><td>0.50</td></tr>
<tr><td>Latrine (Dry climate, groundwater table lower than latrine, small family (3-5 members))</td><td>0.10</td></tr>
<tr><td>Discharge to aquatic environments</td><td>0.11</td></tr>
</table>
</td><td></td></tr>
<tr><td>Fraction of Nitrogen in Protein (F_{NPR})</td><td>0.16</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, equation 6.8 and table 6.11 (IPCC, 2006)</td></tr>
<tr><td>Factor for non-consumed protein added to the wastewater ($F_{NON-CON}$)</td><td>1.4</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, table 6.11 (IPCC, 2006)</td></tr>
<tr><td>Factor for industrial and commercial co-discharged protein into the sewer system ($F_{IND-COM}$)</td><td>1.25</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, table 6.11 (IPCC, 2006)</td></tr>
<tr><td>Nitrogen removed with sludge (N_{SLUDGE})</td><td>0</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, equation 6.8 (IPCC, 2006)</td></tr>
</table>

Part C: Data Sources and Assumptions for Industrial Wastewater Treatment and Discharge

Activity Data/ Emission Factor	Methodological Approach	Data Source
	Activity Data	
Industrial Production (Pi)	**Fertilisers, Textiles, Paper and Pulp, and Petroleum** ◆ Data for these industries is available for the period spanning 2020 to 2070. **Sugar, Meat, Dairy, and Fish Processing:** ◆ The data for these industries is available for the period spanning 2005 to 2022. ◆ Industrial production until 2070 was projected using the following methodology: **GDP and GVA Data Preparation:** ◆ Quarterly real GDP (at 2011-12 prices) was available for 2011-12 to 2023-24 (henceforth referred as 'P_2') but not available from 2005-06 to 2011-12 (henceforth referred as 'P_1'). ◆ Real gross value added (GVA) at 2011-12 prices for 2005-06 to 2023-24 (henceforth referred as 'P_n') was obtained from the Economic Survey 2023-24: Statistical Appendix. ◆ Since, GVA is the total of GDP and subsidies and taxes (s.t), subtracting GDP from GVA for P_2 years provided the subsidies and taxes for the said years. The s.t was correlated with GVA for the years of P_2 and back forecasted for the years of P_1. Since, $(GVA_y = GDP_y + s.t_y)$, *where,* GVA_y is gross value added for a particular year GDP_y is gross domestic for a particular year $s.t_y$ is subsidies and taxes for a particular year y is any particular year	**Fertilisers, Textiles, Paper and Pulp, and Petroleum:** ◆ NITI Aayog, Government of India **Sugar*:*** ◆ National Food Security Mission, Ready Reckoner, Crop Unit-IV, Statistics on Cotton, Jute & Sugar, Page 69 (Ministry of Agriculture and Family Welfare, 2019) ◆ Annexure XXIX, Status Paper on Sugarcane, Directorate of Sugarcane Development, Ministry of Agriculture (Directorate of Sugarcane Development, 2015) ◆ Directorate of Sugar, Department of Food and Public Distribution, Ministry of Consumer Affairs, Food and Public Distribution, GoI (Department of Food and Public Distribution, 2018) ◆ Department of Food and Public Distribution, Ministry of Consumer Affairs, Food and Public Distribution, GoI, Annual Report 2023-24, Page 163 **Dairy**: Basic Animal Husbandry Statistics–2019, Department of Animal Husbandry, Dairying & Fisheries, Government of India

Activity Data/ Emission Factor	Methodological Approach	Data Source
	Thus, $$s.t_y = GVA_y - GDP_y$$ Using this method, the real GDP at 2011-12 prices was obtained for the years of P_1, thereby, ensuring that the real GDP estimates at 2011-12 prices was available for all years of P_n. The actual quantum of meat, dairy and fish production was available from NITI Ayog was available for P_n. The elasticity of production (e) of each year (y) in the period of P_n was calculated using the following formula: $$e_y = \left(\frac{Q_y - Q_{y-1}}{G_y - G_{y-1}}\right) \times \left(\frac{G_{y-1}}{Q_{y-1}}\right)$$ where, e_y is the elasticity of production for a particular year Q_y is the quantum of production in the particular year Q_{y-1} is the quantum of production in the previous year G_y is the GDP in the particular year G_{y-1} is the GDP in the previous year Average elasticity of production (e_{avg}) was calculated which was used to forecast the production values until 2070 based on the GDP forecast until 2070 obtained from NITI Ayog. The following formula was used for this purpose. $$Q_y = \left[e_{avg} \times \left(\frac{Q_{y-1}}{G_{y-1}}\right) \times \left(G_y - G_{y-1}\right)\right] + Q_{y-1}$$	• Basic Animal Husbandry & Fisheries Statistics–2017, Table 1, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture, Government of India • Department of Animal Husbandry and Dairying Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, Annual Report 2023-24, Page 5 **Meat**: • Basic Animal Husbandry Statistics- 2023, Page 20, Department of Animal Husbandry, Dairying & Fisheries, GoI • Basic Animal Husbandry Statistics- 2019, Table 29, Department of Animal Husbandry, Dairying & Fisheries, GoI • Basic Animal Husbandry Statistics- 2014, Table 19, Department of Animal Husbandry, Dairying & Fisheries, GoI • Basic Animal Husbandry Statistics- 2012, Table 22, Department of Animal Husbandry, Dairying & Fisheries, GoI • Basic Animal Husbandry Statistics- 2006, Table 49, Department of Animal Husbandry, Dairying & Fisheries, GoI

Activity Data/ Emission Factor	Methodological Approach	Data Source
		◆ State-wise Meat Production, Handbook of Statistics on Indian States, Reserve Bank of India
		Fish Processing ◆ Handbook on Fisheries Statistics 2014, Table A-2: Fish Production by State/ Union Territories 2000-01 to 2013-14 ◆ Handbook on Fisheries Statistics 2018, Section A–3: State / Union Territory wise Fish Production 2011-12 to 2017-18 ◆ Handbook on Fisheries Statistics 2020, Table 1.2. State/UT wise Inland and Marine Fish production in India for the period 2015-16 to 2019-20 ◆ Handbook on Fisheries Statistics 2022, Table 1.1. Inland and Marine Fish production in India for the period 2019-2021 ◆ Handbook on Fisheries Statistics 2023, Table 1.2. Inland and Marine Fish production in India for the year 2022 **GDP Data:** ◆ Economic Survey of India, 2023-24, Statistical Appendix, Government of India (Ministry of Finance, 2024)
Wastewater generated, m^3/tonnes product (Wi)	◆ Constant values of wastewater generated per tonne of product have been applied for 2030-2070 for all the industry sectors due to lack of year-on-year data. ◆ For the textile sector, wastewater generation standards were sourced from CPCB standards for the discharge of environmental pollutants. ◆ Industry-wise wastewater generated per tonne of product values used are provided below:	**Fertilisers, Sugar, Petroleum, Dairy, Meat, Pulp and Paper, and Fish Processing:** ◆ India Fourth Biennial Update Report (BUR-IV), 2024, Table 2.32 (MoEFCC, 2024) **Textiles*:*** ◆ General Standards for Discharge of Environmental Pollutants Part-A: Effluents, CPCB (CPCB, n.d.)

<table>
<tr><th>Activity Data/ Emission Factor</th><th>Methodological Approach</th><th>Data Source</th></tr>
<tr><td></td><td>
<table>
<tr><th>Industry</th><th>Wastewater generation (m^3/tonne of product)</th></tr>
<tr><td>Fertiliser</td><td>31</td></tr>
<tr><td>Sugar</td><td>1.0</td></tr>
<tr><td>Petroleum</td><td>0.4</td></tr>
<tr><td>Textiles</td><td>120</td></tr>
<tr><td>Dairy</td><td>6</td></tr>
<tr><td>Meat</td><td>13</td></tr>
<tr><td>Pulp & Paper</td><td>143</td></tr>
<tr><td>Fish Processing</td><td>13</td></tr>
</table>
</td><td></td></tr>
<tr><td>Chemical oxygen demand (CODi)</td><td>

Constant values of Chemical Oxygen Demand (CODi) have been used for 2030-2070 for all industry sectors due to lack of year-on-year data
The COD value for textiles was assumed to be same as that of tanneries, as per NATCOM-III, due to the lack of specific data. This approach ensures consistency in emission estimation, given the similarity in organic load characteristics of their wastewater.

<table>
<tr><th>Industry</th><th>COD
(kg COD/m^3)</th></tr>
<tr><td>Fertiliser</td><td>3.00</td></tr>
<tr><td>Sugar</td><td>6.20</td></tr>
<tr><td>Petroleum</td><td>0.50</td></tr>
<tr><td>Textiles</td><td>3.10</td></tr>
<tr><td>Dairy</td><td>4.00</td></tr>
<tr><td>Meat</td><td>4.00</td></tr>
<tr><td>Pulp & Paper</td><td>7.00</td></tr>
<tr><td>Fish Processing</td><td>2.50</td></tr>
</table>
</td><td>
Fertilisers, Sugar, Petroleum, Dairy, Pulp and Paper, Meat and Fish Processing:

India Fourth Biennial Update Report (BUR-IV), 2024, Table 2.32 (MoEFCC, 2024)

Textiles:

India’s Third National Communication and Initial Adaptation Communication, 2023, Table 2.31 (MoEFCC, 2023)

</td></tr>
<tr><td>Organic component removed as sludge (Si)</td><td>0.35</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation Number 6.4 (IPCC, 2006)</td></tr>
<tr><td>Amount of CH_4 recovered (Ri)</td><td>0</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation Number 6.4 (IPCC, 2006)</td></tr>
</table>

<table>
<tr><th>Activity Data/ Emission Factor</th><th>Methodological Approach</th><th>Data Source</th></tr>
<tr><td colspan="3">Emission Factors</td></tr>
<tr><td>Methane correction factor (MCFj)</td><td>

Constant values of MCFj have been used for 2020-2070 for all industry sectors due to lack of year-on-year information.
As the textile and tannery industries both generate wastewater with similar treatment characteristics, the MCF value for emission estimation for both these industries is assumed to be the same , as per NATCOM-III, due to the absence of industry-specific data.
Methane Recovery (%) considered in the industrial wastewater calculations i.e. 70-75% across for Sugar, Meat, Paper and Pulp, Dairy, and textiles industries (overall 45%) is based on NEERI data, assumed to be constant until 2070 under Current Policy Scenario.

Methane recovery data is not available for fertiliser, Fish processing and petroleum industries.
<table>
<tr><th>Industry</th><th>MCF</th></tr>
<tr><td>Fertiliser</td><td>0.3</td></tr>
<tr><td>Sugar</td><td>0.8</td></tr>
<tr><td>Petroleum</td><td>0.3</td></tr>
<tr><td>Textiles</td><td>0.8</td></tr>
<tr><td>Dairy</td><td>0.5</td></tr>
<tr><td>Meat</td><td>0.8</td></tr>
<tr><td>Pulp & Paper</td><td>0.1</td></tr>
<tr><td>Fish Processing</td><td>0.3</td></tr>
</table>
</td><td>Fertilisers, Sugar, Petroleum, Textiles, Dairy, Pulp and Paper, Meat and Fish Processing:

India Fourth Biennial Update Report (BUR-IV), 2024, Table 2.32 (MoEFCC, 2024)

Meat:

2006 IPCC guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge (IPCC, 2006)

</td></tr>
<tr><td>Maximum CH_4 producing capacity (Bo)</td><td>0.25</td><td>2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation Number 6.5 (IPCC, 2006)</td></tr>
</table>

Annexure III: Global Warming Potential of Greenhouse Gases

Greenhouse Gas		100- year Global Warming Potential (GWP) – Second Assessment Report (SAR), 1995	100- year Global Warming Potential (GWP) – Fifth Assessment Report (AR5), 2014
Carbon dioxide	CO_2	1	1
Methane	CH_4	21	28
Nitrous oxide	N_2O	310	265

Source: *IPCC*

Annexure IV: Grid Emission Factors

A "grid emission factor" refers to a CO_2 emission factor (tCO_2/MWh) which will be associated with each unit of electricity provided by an electricity system (Central Electricity Authority, 2021). The following table presents the emission factors (estimated by NITI Aayog) used for estimating the impacts of electricity generation from the processing of waste on overall emissions in Current Policy Scenario and Net Zero Scenario.

Scenario	Unit	2050	2070
Current Policy Scenario (CPS)	tCO_2/(MWh)	0.33	0.07
Net Zero Scenario (NZS)		0.26	0.00

Source: *NITI Aayog*

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सत्यमेव जयते

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