GHG Platform INDIA

Briefing Paper

OPPORTUNITIES FOR REDUCTION OF GHG EMISSION FROM DOMESTIC WASTEWATER TREATMENT IN URBAN AREAS:

A BRIEF ORIENTATION FOR DECISION-MAKERS

ICLEI Local Governments for Sustainability SOUTH ASIA

About GHG Platform India

The GHG Platform India is a collective civil society initiative providing an independent estimation and analysis of India's Greenhouse Gas (GHG) emissions across key sectors, namely, Energy, Industry, Agriculture, Livestock, Forestry, Land-use and Land-use change, and Waste. The platform comprises notable civil society groups in the climate and energy space in India- Council on Energy, Environment and Water (CEEW), Center for Study of Science, Technology and Policy (CSTEP), ICLEI - Local Governments for Sustainability, South Asia, Vasudha Foundation and World Resources Institute-India. The platform was jointly conceptualized by Shakti Sustainable Energy Foundation along with partners.

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1. ABOUT THE PAPER

This paper is developed as part of GHG Platform India, a collective civil-society initiative providing an independent estimation and analysis of greenhouse gas (GHG) emissions in India across sectors, namely energy, industry, agriculture, livestock, forest, and waste.

This paper discusses about the GHG emissions and mitigation opportunities related to domestic wastewater in India. The objective of this paper is:

- To reflect GHG emission trends and drivers for domestic wastewater in the Indian context, with a specific focus on urban areas
- To identify recommendations towards mitigation or reduction of GHG emissions from Urban Domestic Wastewater, with a specific focus on implications of adoption of aerobic and anaerobic treatment based solutions.

The target readers of the paper are decision-makers, policy developers, Urban Local Bodies (ULBs), practitioners, experts and researchers.

2. BACKGROUND

2.1. Global Warming and Climate Change

The average near-surface atmospheric temperature of the Earth has increased from 0.2oC to 0.6oC in the 20th century (IPCC, 2007).The last decade (i.e., 2012-2022) is the warmest on record. An increase in GHG emissions is causing global warming that is altering the Earth's climate system and leading to climate change, posing risks to humankind and life on the Earth. The key impacts of climate change include:

- High-intensity rainfall and floods with increasing moisture evaporation due to high temperatures, causing risks to infrastructure and human lives along with economic losses.
- Droughts exacerbating the water scarcity and risks to agriculture productivity, resulting in challenges to water and food security.
- Rising sea levels that threaten the lives of the coastal and island communities.
- Increasing vulnerability of and risks to human health due to climate change and extreme weather conditions that lead to growth in vector-borne diseases.
- Rising temperatures in urban areas also have a significant impact on waste management as the rate of degradation of solid waste is higher at the landfill sites, leading to GHG emissions and leachate of contaminates into the groundwater.
- Variations in rainfall, sea level rise and increased temperature extremes impact the wastewater treatment infrastructure by reducing carrying capacity due to infiltration of stormwater, increased stagnation of wastewater and enhanced corrosion in sewer pipes resulting from extensive anaerobic decomposition (Hughes, Cowper-Heays, Olesson, Bell, & Stroombergen, 2021).

To address climate change and its impact, the Paris Agreement was adopted in 2015 globally. The Paris Agreement aims to limit global warming to well below 2oC, and preferably to 1.5oC, compared to pre-industrial levels. The Agreement is a key multilateral climate framework that brings all nations together to collectively undertake ambitious efforts to combat climate change and adapt to its effects. Under the Paris Agreement, countries are required to determine their climate commitments, in terms of Nationally Determined Contributions (NDCs), while reporting regularly on GHG emissions and implementation of climate actions. To contribute to accelerated climate action and drive its domestic efforts, India announced its target of 'Net-zero GHG emissions' by 2070 at the 26th Conference of Parties (COP-26) at Glasgow in 2021 (Press Information Bureau, 2021).

2.2. Emission of Greenhouse Gases

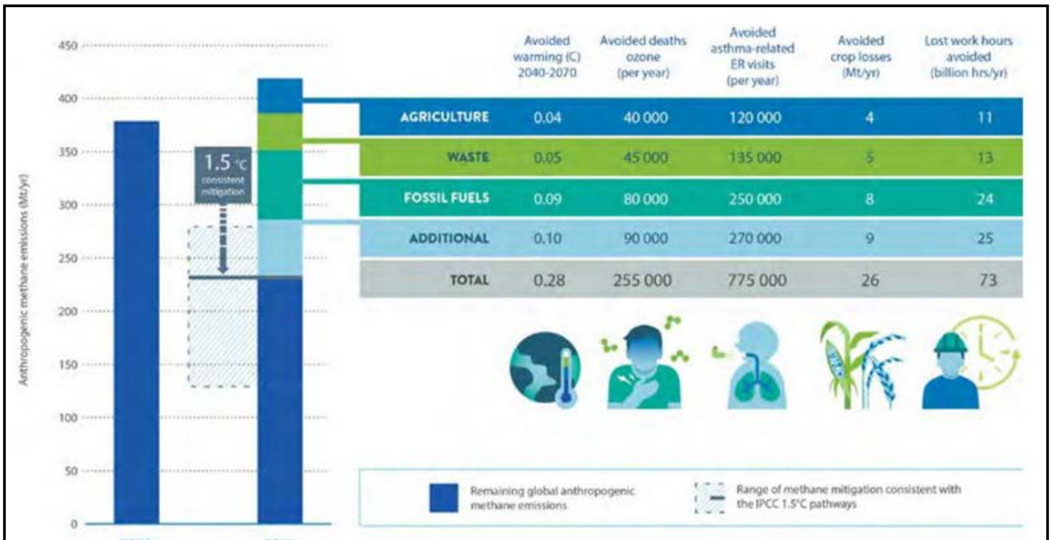
It is an accepted fact that anthropogenic activities contribute majorly to GHG emissions, leading to global warming (IPCC, 2018). The key GHGs include carbon dioxide (CO_2), methane (CH_4) and Nitrous Oxide (N_2O). GHG emissions are measured as the total amount of CO_2, CH_4 and N_2O emissions from an activity or system. The GHGs warm the earth by absorbing solar energy and slowing down the rate at which the solar energy escapes into space. The effect of GHG gases on global warming is based on radiative efficiency i.e., the ability to absorb energy and the period of their presence in the atmosphere. The Global Warming Potential (GWP) is used to measure the warming impact of different GHG gases, calculated based on the energy absorption ability and time period of 100 years. The GWP factors for CO_2, N_2O and CH_4 over a 100-year horizon as per the IPCC sixth assessment report are given in the table below. The GWP of CH_4 is high due to its high ability to absorb solar energy and that of N_2O is high due to the longer time period of its existence in the atmosphere.

Table 1: Global Warming Potential (GWP) as per IPCC assessment

GHGs	GWP (100-year period)
CO_2	1
CH_4 (fossil origin)	29.8
CH_4 (non-fossil origin)	27.2
N_2O	273

CH_4 accounts for 17.3% of global emissions while contribution of N_2O stands at 6.2% (Climate Watch, 2020). CH_4 is also short-lived climate pollutant (SLCP) due to its nature with an atmospheric lifetime of about 12 years. Short-lived climate pollutants (SLCP) are gases in the atmosphere that remain for a much shorter period of time than carbon dioxide (CO_2), yet their potential to warm the atmosphere is many times greater. Therefore, CH_4 is considered as the second most anthropogenic GHG after CO_2 contributing to one-third of today's anthropogenic GHG warming. As per IPCC 2013 assessment, CH_4 concentrations are above desired levels in the 2°C scenarios, indicating the urgency towards mitigation and reduction of CH_4 emissions. The Paris Agreement's 1.5°C targets cannot be achieved without reducing CH_4 emissions.

Figure 1 presents the current and projected anthropogenic CH_4 emissions, with mitigation potential identified across sectors in order to achieve a 1.5° C target by 2030, along with co-benefits. It can be seen that systematic mitigation of CH_4 emissions in the Waste sector will avoid nearly 0.05°C of global warming by the 2040s and complement all long-term climate change mitigation efforts. It would also prevent 45,000 premature deaths, 135,000 asthma-related hospital visits, 13 billion hours of lost labour from extreme heat, and 5 million tonnes of crop losses each year globally.

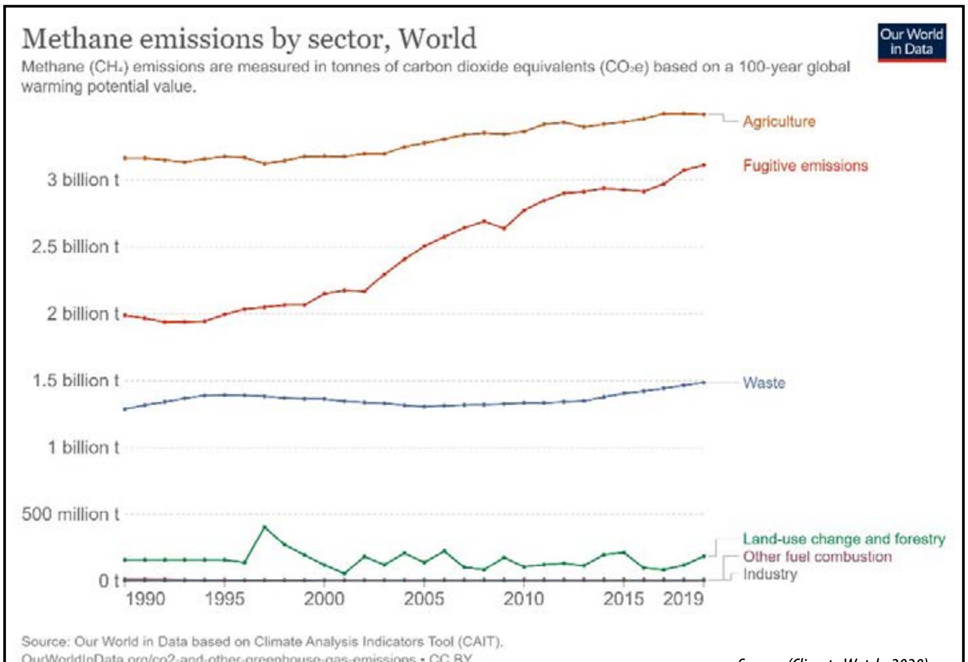


Source: (UNEP & Climate and Clean Air Coalition, 2021)

Figure 1: Current and projected anthropogenic methane emissions and sectoral mitigation potential in 2030

2.3. GHG Emissions from the Waste Sector

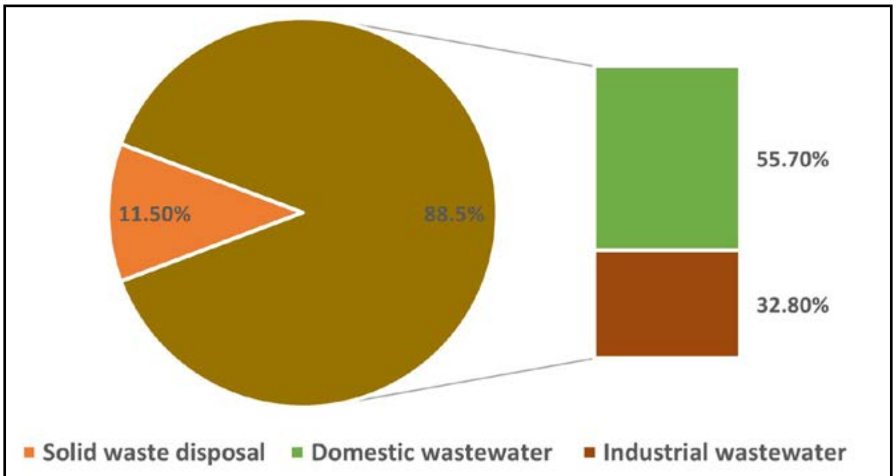
The Waste sector accounts for 3.2% of the total global GHG emissions which primarily includes emissions from solid waste disposal (1.9%) and from wastewater (1.3%) (Climate Watch, 2020). Landfills and disposal sites are usually low-oxygen environments, in which organic matter is converted to CH_4 when it decomposes. When organic matter from wastewater generated by humans decomposes during discharge and treatment of wastewater, it produces CH_4 and N_2O. Wastewater in particular, contributes to between 7-10% of global anthropogenic CH_4 (McKinsey Sustainability, 2021). Based on the Climate Analysis Indicators Tool (CAIT), global GHG emissions from the Waste sector have increased steadily from 1.36 billion tonnes CO2e in 1990 to 1.49 billion tonnes CO2e in 2019 (see Figure 2).



Source: (Climate Watch, 2020)

Figure 2: Global methane emissions by Sector (1990- 2019)

For India, the Waste sector contributed to 2.65% of national GHG emissions in 2016 as per India's 3rd Biennial Update Report. This includes GHG emissions as a result of microbiological processes that occur in the organic matter of solid waste under anaerobic degradation, and from the treatment and discharge of domestic and industrial wastewater. Based on GHG Platform India estimates, GHG emissions from the Waste sector in India amount to 114.49 million tonnes of CO2e in 2018. Wastewater is the largest contributor, with 55.7% of GHG emissions resulting from domestic wastewater and industrial wastewater accounting for 32.8% of the Waste sector emissions (see Figure 3). Solid waste disposal contributes to 11.5% of the GHG emissions from Waste sector. Therefore, addressing and reducing GHG emissions from domestic wastewater is important to help realise India's climate goals.



Source: (GHG Platform India, 2022. Waste Sector GHG Emissions)

Figure 3: Sub-sector wise share of GHG emission from the Waste sector in India, 2018

3. GHG EMISSIONS FROM DOMESTIC WASTEWATER

GHG emission from domestic wastewater depends on the aerobic and anaerobic processes taking place in wastewater management systems. Aerobic process is defined as the decomposition of organic compounds present in wastewater into stable compounds such as Nitrates, Carbon dioxide and Sulphates (in a few cases), in the presence of free dissolved oxygen, through aerobic micro-organisms, emitting CO_2. This includes treatment technologies such as aeration tanks, oxidation ponds, activated sludge process, contact beds and intermittent sand filters.

Anaerobic process is the decomposition of organic compounds present in wastewater into stable compounds like Nitrogen gas, Ammonia, CO_2, Hydrogen Sulphide and CH_4 in the absence of free dissolved oxygen carried out by anaerobic micro-organisms. In this process, the bounded oxygen from nitrates and sulphates present in wastewater is used for decomposition. The treatment technologies with respect to the anaerobic process include septic tanks, advanced septic tanks, sludge digestion tanks, and anaerobic lagoons, among others.

The GHG emissions from treatment and discharge of domestic wastewater include CO_2, CH_4 and N_2O. CO_2 emission from wastewater treatment plants is not considered in the Intergovernmental Panel on Climate Change (IPCC) calculation methods and guidelines, as it is considered to have a biogenic origin. The GHG emissions from wastewater treatment and discharge can be categorised into:

Direct GHG emissions

- **CH_4:** Wastewater and its sludge components can produce CH_4 if it degrades anaerobically. The generation of CH_4 depends primarily on the quantity of degradable organic material in the wastewater, temperature, and the treatment system. Sources of CH_4 emission in wastewater handling include conveyance, sewerage treatment and common effluent treatment plants.
- **N_2O:** Degradation of nitrogen components in wastewater, e.g., urea, nitrate and protein, leads to emission of N_2O. Centralised wastewater treatment systems may include a variety of processes, ranging from lagoons to advanced tertiary treatment technology for removing nitrogen compounds. After being processed, treated effluent are discharged into a water resource (e.g., river, lake, estuary). Direct emissions of N_2O may be generated during both nitrification and denitrification of the nitrogen present. Both processes can occur in the plant and the water body receiving the effluent. Nitrification is an aerobic process converting ammonia and other nitrogen compounds into nitrate. Denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into dinitrogen gas. N_2O can be an intermediate product of both processes, but is more often associated with denitrification.

Based on estimates from the GHG Platform India, it is observed that emissions of CH_4 contributed to 73% of the total direct GHG emissions from domestic urban wastewater in 2018, with the remaining 27% contributed by N_2O gas.

Indirect emissions

- **CO_2:** Non-biogenic CO_2 production due to electricity consumption in the treatment process and fuel usage in faecal sludge collection and transportation as part of the faecal sludge management system.

Table 2 provides an overview of the sources of CH_4 and N_2O emission across domestic wastewater systems. The quantification of emissions from all sources is essential for developing strategies to control and reduce the rate of increase in emissions.

Table 2: GHG emissions during on-site and off-site wastewater management

System type	Type of wastewater pathway	Mode	Potential sources
Off-Site / Centralized system	Collected	Sewer closed/ under ground	Not a source of CH_4/ N_2O.
		Open drains/sewer	Stagnant, overloaded open collection sewers or ditches/ canals are likely significant sources of CH_4.
	Uncollected	Discharge to lakes and rivers	Stagnant, oxygen-deficient rivers and lakes may allow for anaerobic decomposition to produce CH_4. Rivers, lakes and estuaries are likely sources of N_2O

System type	Type of wastewater pathway	Mode	Potential sources
	Treated	Aerobic treatment	• May produce limited CH_4 from anaerobic pockets. • Poorly designed or managed aerobic treatment systems produce CH_4. • Advanced plants with nutrient removal (nitrification and denitrification) are small but distinct sources of N_2O. • Sludge may be a significant source of CH_4 if emitted CH_4 is not recovered and flared.
		Anaerobic treatment	Significant source of CH_4 if emitted CH_4 is not recovered and flared.
	Un-treated	River/lake discharge	Stagnant, oxygen-deficient rivers and lakes may allow for anaerobic decomposition to produce CH_4. Rivers, lakes and estuaries are likely sources of N_2O.
		Stagnant Sewers	Stagnant, overloaded open collection sewers or ditches/ canals are likely significant sources of CH_4.
On-Site System	Collected	Septic tanks and pit latrines – Anaerobic treatment	Irregular maintenance can increase methane CH_4 emissions.

Source: Author's analysis based on 2006 IPCC Guidelines

As per the United Nations Environment Programme and Climate and Clean Air Coalition (2021), the Waste sector holds the largest potential for methane mitigation in India. Additionally, a recent report by McKinsey has estimated that emissions from the wastewater sector could be reduced 27% by 2030 and 77% by 2050 through the expansion of modern sanitation infrastructure and technology (McKinsey Sustainability, 2021).

India's NDC reports that 40% of its population would be urbanised by 2030 and will contribute to as much as 75% of the GDP. About 50% additional infrastructure, as compared to 2014, is to be built to meet the requirements of India's projected population in 2030. The country's urban population is further expected to double by 2050 from 2018 levels, adding about 416 million urban dwellers over this period (United Nations, 2018). Urban growth is estimated to be responsible for 73% of the rise in total population from 2011 to 2036 (Ministry of Health & Family Welfare, 2020). Indian cities face a significant challenge to provide and improve infrastructure and delivery of municipal services adequately across energy, housing, water, waste management, and transport in order to ensure that this urban growth is sustainable, equitable and at the desired quality. Further, in recent years Indian cities have been greatly affected by the impacts of climate change, ranging from flooding, heat waves to water scarcity which have impacted the proper functioning of existing sewer networks as well as the scientific treatment and management of on-site wastewater treatment systems. The sewer networks in such cities are often overloaded with wastewater and stormwater, leading to untreated wastewater flowing into rivers, lakes or coastal areas.

Hence, there is need to closely assess the accessibility and use of different treatment systems and pathways for domestic wastewater in urban areas. Such an assessment can help ensure more efficient collection and management of urban domestic wastewater as well as help understand opportunities and potential for decarbonization of the wastewater sector in the long-term.

4. DOMESTIC WASTEWATER MANAGEMENT IN URBAN INDIA

The Central Pollution Control Board estimated that domestic wastewater generated in India is about 72,368 MLD in 2021 (CPCB, 2021). The IPCC categorizes two major pathways for handling of wastewater generated from households, consisting of centralised/off-site systems (these include sewage treatment plants) and on-site treatment systems that include pit latrines and septic tanks (see Figure 4).

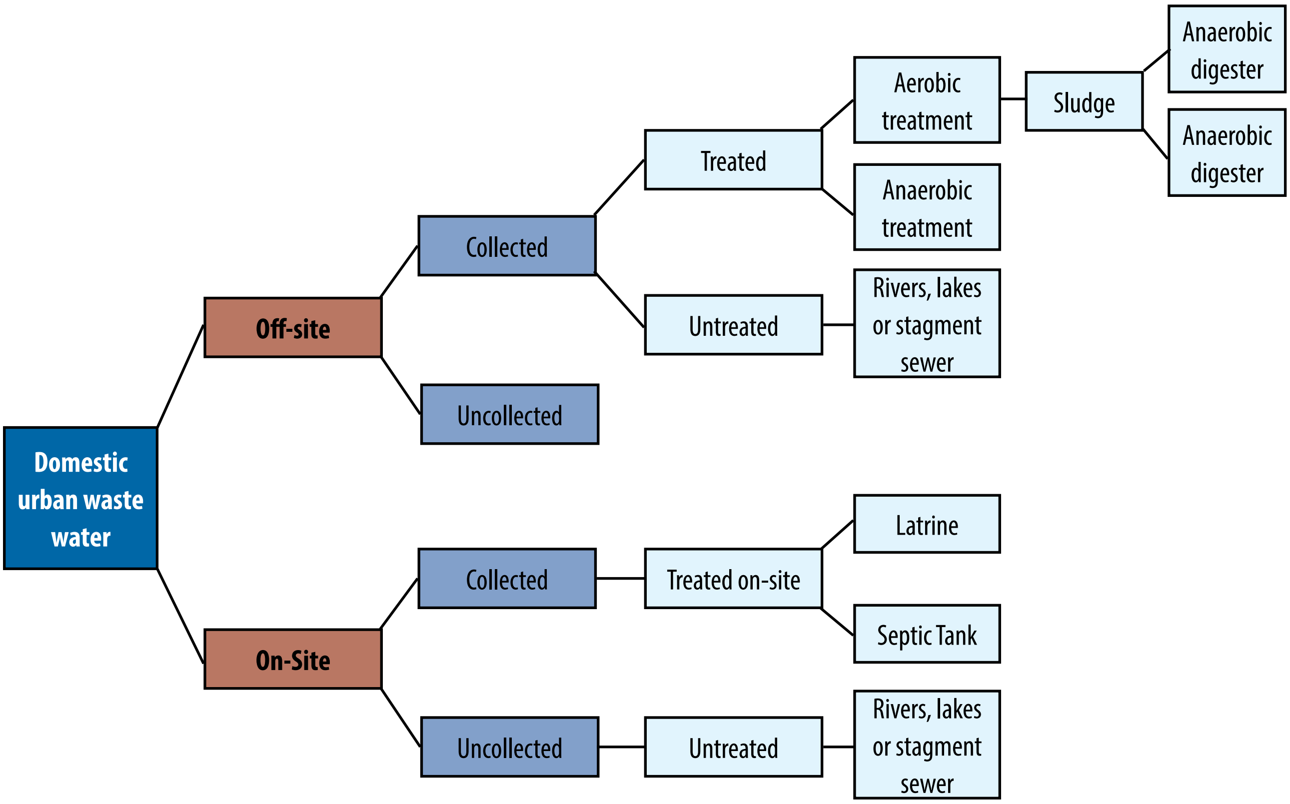


Figure 4: Domestic Wastewater management pathways as per IPCC

Centralized or off-site wastewater treatment and discharge systems

As per Census 2011 only 32.7%% of urban households in India are reported to be connected to sewer networks (Census of India , 2011). Of the total wastewater that is generated (72,366 MLD in 2020-21), only 28% is collected and treated (i.e. 20,235 MLD) and the remaining volume is either uncollected or is let-out as untreated wastewater from the sewers (CPCB, 2021). The portion of urban wastewater that is collected in sewers but remains untreated is handled either through 'stagnant sewers' or is discharged into water bodies such as 'sea, lake or river'. Such untreated wastewater often stagnates and also leads to GHG emissions.

The CPCB reports indicate that of the 1,631 Sewerage Treatment Plants (STPs) in the country, only 1,093 STPs are operational as of 2020-21. About 102 STPs are non-operational, 274 are under construction and 162 STPs are in the proposed stage. Out of 1,093 operational STPs, only about 578 STPs with a combined capacity of 12,197 MLD conform to environmental standards for discharge outlined by CPCB and SPCBs. Thereby, less than half of the volume of wastewater handled by operational STPs (i.e. 26,869 MLD) does not get treated adequately (see Figure 5).

This reflects inadequate operations of the wastewater treatment facilities. Based on 2006 IPCC Guidelines, STPs that are inadequately managed lead to higher CH_4 emissions (given that the 'methane correction factor' value is 0.3 for 'not well managed aerobic systems') as compared to well-managed aerobic STPs that are envisaged to have zero CH_4 emissions (due to MCF of 0) (Chaturvedula, Kolsepatil, & Sangem, 2016). Given that about 91% of existing 1,631 STPs in the country use aerobic wastewater treatment systems, their inefficient operations and performance of STPs results in significant contribution to GHG emissions.

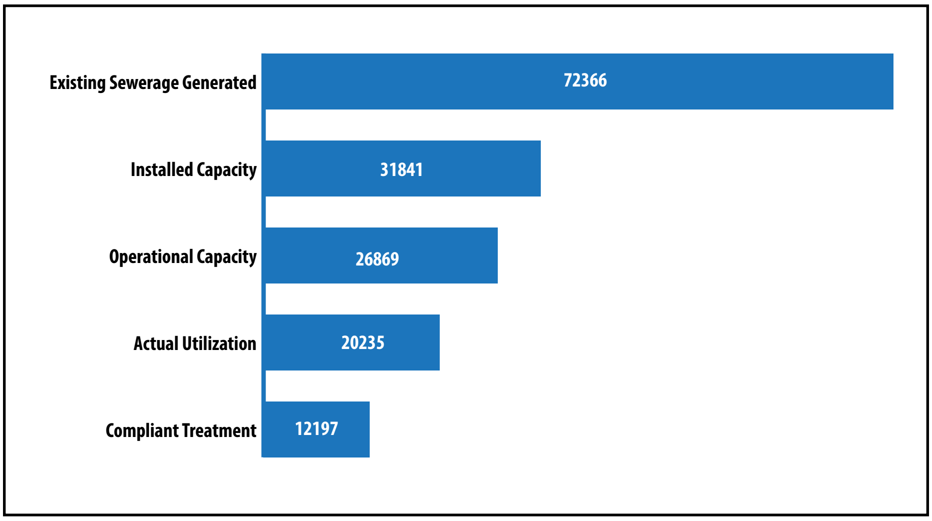


Figure 5: Status of Domestic Wastewater Generation and Treatment in Urban Centres in India, 2020-21

On-site wastewater treatment and discharge systems

Census 2011 reports that 81.4% of urban households had toilet facilities within their premises. Of these urban households, 32.7 % relied on water closets connected to the sewer system and 38.2% of households used water closets with septic tanks. The remaining households are assumed to use pit latrines and other unsanitary systems. These on-site sanitation systems are primarily anaerobic and, if not scientifically managed, can adversely lead to GHG emissions.

Some of the factors or uncertainties that can impact the GHG emissions from on-site sanitation systems are:

- Poor construction quality of the septic tanks and soak pits that does not adhere to standards specified by the Bureau of Indian Standard (IS: 2470), leading to scientifically untreated waste water and sludge, resulting in methane emissions
- No existing mechanism in place for safe collection, transportation, treatment and disposal of accumulated sludge in septic tanks, which hampers its treatment performance
- Unregulated disposal of faecal sludge and septage by unorganised private de-sludgers in open land and water bodies without any treatment

Decentralised waste water sanitation systems (DEWATs) have emerged as a solution for improving wastewater management in the absence of connectivity to sewer network. Adoption of DEWATs is still at the nascent stage in India, being mostly implemented at pilot scale, with at scale deployment needed.

In addition to these factors related to the management of on-site and off-site treatment systems, the rapid increase in urban population is expected to put a significant strain on the existing wastewater treatment infrastructure resulting in the increase in from proportion of GHG emissions from the urban domestic wastewater sector. For instance, with urban density as high as 26,645 persons/sq. km as of 2020-2021 in populous cities like Mumbai (Brihanmumbai Municipal Corporation, 2021), the per capita GHG emissions from urban domestic wastewater is estimated to be 53.46 kg CO2e.[1]

1 If you need assistance joining the Campaign, please visit: https://mcr2030.undrr.org/dashboard-guide/local-government/how-to-join

5. COMPARISON OF AEROBIC AND ANAEROBIC WASTEWATER TREATMENT SOLUTIONS

GHG emissions from wastewater depend on the treatment technologies that are adopted, as noted previously in this document. This section includes a comparison of aerobic and anaerobic treatment technologies with relevance to GHG emissions (see Table 3).

Table 3: Comparison of aerobic and anaerobic treatment technologies

Parameters	Aerobic treatment	Anaerobic treatment
Treatment efficiency[(a)]	The treatment efficiency ranges from 75–98%	The treatment efficiency ranges from 51–96%
Electricity consumption[(b)]	Relatively high, due to the electricity required to supply sufficient dissolved oxygen for removal of organic matter	Relatively low-anaerobic treatment does not require additional oxygen and relevant electricity
Sludge yield[(c)]	The amount of sludge generation is relatively high. From 1 kg COD removal about 0.4 to 0.6 kg sludge is produced with aerobic treatment.	The amount of sludge generation is low. From 1 kg COD removal 0.03 to 0.15 kg is produced with anaerobic treatment.
Potential for energy recovery towards reduction of GHG emissions[(d)]	-	Anaerobic treatment generates methane gas, which if recovered can be a source of energy production. Methanation of 1 kg COD can produce about 3,300 Kcal of energy.
Potential for mitigation of GHG emissions[(e)]	Well-managed aerobic STPs have zero CH_4 emissions (due to MCF of 0)	Methane capture is possible

Source: (a) (Cakir & Stenstrom, 2005); (b) (Ranieri, Giuliano, & Ranieri, 2021) ; (c) & (d) (Kobayashi, 2013); (e) (IPCC, 2006)

Aerobic and anaerobic systems are quite similar in terms of treatment efficiency in well-managed and operational conditions. Aerobic decomposition requires a proportionate volume of dissolved oxygen to the volume of organic matter in the wastewater. The electricity required to supply sufficient dissolved oxygen accounts for a major proportion of the electricity requirement in aerobic treatment technology. About 1.1 kWh of electricity is needed to treat 1 kg of COD (Chemical Oxygen Demand: a measurement unit for organic matter) in wastewater treatment facilities . On the other hand, anaerobic treatment does not need additional oxygen and therefore does not require additional electricity for supplying such oxygen. Although both aerobic and anaerobic treatment processes use electricity for stirring and pumping operations, these operations require relatively less power. Thus, anaerobic treatment is considered to have lower electricity consumption and is relatively easier to control, creating an opportunity for mitigation of indirect GHG emissions from use of electricity.

The sludge yield or output sludge quantity in anaerobic treatment technology is comparatively lower than aerobic treatment technology. The amount of excess sludge generation from 1 kg COD removal is 0.4 to 0.6 kg with aerobic treatment, and 0.03 to 0.15 kg with anaerobic treatment. Therefore, the fact that anaerobic treatment generates much smaller amount of waste, offers another advantage of reducing the cost of sludge treatment and quantity of GHG emissions. Furthermore, that anaerobic treatment generates CH_4 gas adds to its advantages. The CH_4, if recovered, can be a source of energy that can be accounted towards reduction of GHG emissions. Methanation of 1 kg COD can produce about 3,300 kcal of energy (Kobayashi, 2013). The high amount of sludge generated by aerobic treatment systems is often left untreated and disposed of in an unsanitary manner. Even mixed anaerobic or aerobic systems lead to lower sludge production than that of an exclusively aerobic system. About 90% of wastewater treatment plants in the country employ aerobic treatment systems and scientific treatment and disposal of sludge is nearly absent.

In comparison to aerobic treatment technology, the key disadvantage of anaerobic treatment technology is the relatively low microbial growth rate. Anaerobic treatment requires higher influent concentration to achieve reasonable concentration of microorganisms retained in the reaction tank. When the influent concentration is above a certain level, the concentration of anaerobic microorganisms in the reaction tank becomes saturated. On the other hand, when the influent concentration is low, the reaction tank cannot retain a sufficient number of microorganisms to ensure satisfactory performance because of their low growth yield. However, anaerobic technologies such as the up-flow Anaerobic Sludge Blanket (UASB) method, which is relatively new anaerobic technology, have better microbial growth rates. UASB consists of an up-flow reactor with a reverse funnel-shaped gas-liquid-solid separator, enabling retention of an optimum concentration of anaerobic microorganisms and addressing the issue of low microbial growth rate.

About 8.7% of sewage treatment facilities in India use anaerobic technologies, treating about 4,351 MLD of wastewater in total. USAB is the prevalent anaerobic treatment technology being used, accounting for 81% of total anaerobic treatment capacity installed in the country (treatment capacity of 3,562 MLD across 76 STPs) (Refer Annexure 1). In order to scale up, adoption of anaerobic systems, further viability assessment of existing treatment facilities for parameters such as land requirement, operation and maintenance cost, and capital cost is essential for mitigation. This will contribute to adoption and scale up of anaerobic technologies through informed decision-making towards GHG emission reduction in urban areas.

5.1. Electricity consumption in Aerobic and Anaerobic wastewater treatment

The table below gives an overview of electricity requirements for aerobic and anaerobic treatment technologies adopted in India at present. Aerobic treatment plants are observed to have relatively higher electricity consumption compared to anaerobic treatment plants. Considering the daily power requirement of anaerobic treatment solutions including Activated Sludge Process (ASP), Moving Bed Biological Reactor (MBBR) and Sequential Batch Reactor (SBR) technologies, the average power consumption for aerobic treatment technology is 187.7 kWh/day/MLD. The UASB technology is an anaerobic treatment process with relatively lower energy consumption, estimated to stand at about 125.7 kWh/day/MLD.

Table 4: Assessment of electricity consumption across aerobic and anaerobic wastewater treatment technology

Electricity requirement – kilowatt-hour/day/million litres per day (kWh/day /MLD)	ASP*a	MBBR*b	SBR*a	MBR*a	WSP**b	UASB+ASP*b
Details	**Aerobic treatment technologies**			**Anaerobic treatment technologies**		
Average Technology Power Requirement - Secondary Treatment + Secondary Sludge Handling	180	220	150	300	2	120
Average Technology Power Requirement - Tertiary Treatment + Tertiary Sludge Handling	1	1	1	1	1	1
Average Non-Technology Power– Requirement - Secondary Treatment	4.50	2.50	2.50	2.50	2.50	4.50
Average Non-Technology Power Requirement - Tertiary Treatment	0.20	0.20	0.20		0.20	0.20
Total Daily Power Requirement (average)	185.70	223.70	153.70	302.50	5.70	125.70
Resulting indirect GHG emission from power consumption (tCO_2e)	152,791	184,057	126,462	248,892	4,690	103,424

Note : Sludge Treatment: * Thickener + Centrifuge; ** Drying Process | Processing type–Type - a Aerobic; b Anaerobic-Aerobic; | ASP : Activated Sludge Process | MBBR : Moving Bed Biological Reactor | SBR : Sequential Batch Reactor | UASB : Upflow Anaerobic Sludge Blanket | EA : Extended Aeration | MBR : Membrane Bio Reactor | WSP : Waste Stabilization Pond

Source: (IIT, 2010)

1.11. Measures to reduce energy consumption

The following measures can help to improve energy efficiency and reduce energy consumption, in both existing as well as new wastewater treatment facilities.

- Enhancement of motor efficacy: Actions such as using appropriate motor capacity, use of sensor and automated technologies for efficient use of motors, use of Variable Speed Drive; periodical lubrication and maintenance.

- Enhancing the pumping efficiency:
  - Proper maintenance of pumps
  - Monitoring to determine blockage, clogged or gas-filled pumps or pipes, impeller damage, inadequate suction, operation outside preferences, or worn out pumps, leading to excess use of energy.
  - Use of Variable Frequency Drives to match the speed of pump to variable flow conditions.
  - Provision of remote controls enable pumping systems to be started and stopped relatively quickly and accurately.
- Enhancing the aeration efficiency in case of aerobic treatment systems
  - The oxygen added to the aeration process should be controlled and adjusted using IT based measurement systems considering the variability of the influent wastewater.
  - Provision of intermittent aeration assists in energy savings by reducing the operation hours of aeration system. This methodology involves momentarily stopping air flow to an aeration zone or cycling air flow from zone to zone.
  - Provision of automated dissolved oxygen control can help in achieving significant energy saving.
  - Replacement of coarse bubble diffusers with fine bubble diffuser reduces the energy consumption in blowers of aerators.
- Wastewater treatment plants should be designed preferably with gravity flow which requires lesser pumping and in turn reduces the energy consumption for pumping. Although, topography of the service area can be a constraint while considering this criterion.
- Regular energy audits should be carried out to optimize energy management and performance.
- Renewable energy solutions such as solar PV can be deployed at wastewater treatment facilities, with sufficient rooftop and land space available at such facilities. Integration of renewable energy can help reduce consumption of grid-electricity and also provide a clean reliable source of power in the event of power cuts.

6. EXISTING POLICY ENVIRONMENT FOR URBAN WASTEWATER MANAGEMENT

Considering' India's existing policy environment and initiatives being undertaken to address existing gaps in wastewater management, notable opportunities and potential exists to decarbonise the domestic wastewater sector, particularly in urban areas.

Based on the National GHG Inventory, India was able to reduce the emission intensity (excluding emissions from agriculture sector) of its GDP by 24% between 2005 and 2016 (MoEFCC, 2021). Recently, India updated its first NDC to raise its ambitions to reduce emissions intensity of its GDP by 45%[2] by 2030 from 2005 levels. In order to achieve this goal, India's developmental policies and programmes continue to place emphasis on economic development and sustainable environmental management. Hence, while India is focusing on rapid expansion and modernisation of sanitation for improving the living conditions of its citizens, there are potential co-benefits that emanate such as emission reductions as well as enabling conversion of faecal sludge as manure or other usable forms, such as energy. Key policies and programmes with implications on GHG emissions from wastewater management in India include:

National Mission on Sustainable Habitat (NMSH) 2.0.
The Government of India launched the National Action Plan for Climate Change (NAPCC) in 2008 with eight sub-missions representing the multi-pronged, long-term, and integrated strategies to mitigate and adapt to the adverse impact of climate change. The plan aims at fulfilling India's developmental objectives with a focus on reducing the emission intensity of its economy. One of the missions under the NAPCC is the National Mission on Sustainable Habitat.

2 Previously India had committed to reducing emission intensity of its GDP by 33-35% by 2030 from 2005 level

The first version of NMSH released in 2010, has now been revised in the context of the NDC, SDGs and the New Urban Agenda (2021-2030). The Sustainable Habitat has been defined as *'an approach towards a balanced and sustainable development of the ecosystem of habitat which offers adequate shelter with basic services, infrastructure, livelihood opportunities along with environmental and socio-economic safety including equality, inclusiveness and disaster-resilience'* (MoHUA, 2021).

Under this mission, key mitigation and adaptation strategies are being implemented under various thematic areas. The thematic area on 'Water management' focuses on augmenting existing water resources by recycling/reuse of treated sewage water, and promoting circular economy of water through the development of City Water Balance Plans). One of the key strategies the mission focuses on encouraging 100% recovery of operation and maintenance (O&M) charges by water supply authorities and wastewater management. This is aimed at ensuring a sustainable business model for the establishment of efficient wastewater treatment systems.

Swachh Bharat Mission- Urban (SBM-U)
SBM-U was launched in 2014 with the objectives of helping all statutory towns achieve 100% Open Defecation Free (ODF) status and to bring about behavioural change by 2019. The mission has achieved significant success in terms of increasing access to toilets.

In 2021, Swachh Bharat Mission-Urban 2.0 (SBM-U 2.0) was launched with a focus on achieving ODF+ status for all statutory towns and all cities with less than 100,000 population. The Ministry of Housing and Urban Affairs, Government of India has introduced ODF++ and Water+ protocols which focus on addressing safe containment, evacuation, transportation and processing of faecal sludge from toilets and ensuring that no untreated sludge is discharged into open drains, water bodies or in open fields. The vison statement of SBM-U 2,0 is given below

"All used water including faecal sludge, especially in smaller cities are safely contained, transported, processed and disposed so that no untreated faecal sludge and used water pollutes the ground or water bodies."

SBM-U 2.0 is expected to play a crucial role in achieving 100% treatment of wastewater before discharge into water bodies, and maximum reuse of treated wastewater, which is an immediate step towards GHG mitigation.

Atal Mission for Rejuvenation and Urban Transformation (AMRUT)
The objective of AMRUT 2.0 (2021-2025) is to provide 100% coverage of sewerage and septage in 500 AMRUT cities, through provision of 26.4 million sewer or septage connections. It also aims to recycle and reuse treated wastewater to cater to 20% of total water requirements of the cities and to serve about 40% of industrial demand.

The AMRUT program targets the development of a value chain from capture to treatment of wastewater, helping support reduction of GHG emissions due to leakage of wastewater into the environment. In addition to this, AMRUT also gives the indirect opportunity to reduce GHG emissions in the Water sector, by catering to water demand through recycled water. The Mission has so far completed projects on networked underground sewerage systems, augmentation and rehabilitation of old sewerage systems, STPs, tertiary treatment reverse osmosis plants, faecal sludge treatment plants, and mechanical and biological cleaning of sewers/septic tanks (MoHUA, 2021).

National Policy on Faecal Sludge and Septage Management
The policy aims to ensure that all Indian cities and towns become totally sanitised, healthy and liveable and ensure sustainable onsite sanitation services together with faecal sludge and septage management to achieve optimum public health status and maintain a clean environment with special focus on the poor.

This policy has created a supporting policy environment for regulation of on-site sanitation systems, leading to the opportunity for mitigation of GHG emissions from untreated or uncollected wastewater, particularly with respect to on-site sanitation systems.

Smart Cities Mission

A key feature of the Smart Cities Mission, launched in 2015, is that it aims to drive economic growth and improve the quality of life of people by enabling local area development and harnessing smart and effective technologies. The Smart Cities Mission allows for pilots to be deployed in select priority area of specified sizes for either redevelopment, retrofitting and greenfield development. With regard to domestic wastewater technologies, this provides an opportunity to apply smart solutions such as DEWATs or anaerobic sewage treatment plants to improve wastewater management systems.

7. TRENDS AND DRIVERS OF CH_4 EMISSIONS FROM URBAN DOMESTIC WASTEWATER

7.1. Trend of GHG Emissions from Domestic Wastewater

GHG emissions from domestic wastewater in India amounted to 63.76 million tonnes of CO2e in 2018 as per GHG Platform India estimates. Emissions from rural domestic wastewater contributed to 61% of the aggregate domestic wastewater emissions, with urban areas accounting for the remaining 39% of emissions. GHG emissions from urban domestic wastewater have increased at a higher rate as compared to rural wastewater, rising at a Compound Annual Growth Rate (CAGR) of 3.5% from 2005 to 2018 (see Table 5). Over the same period, rural domestic wastewater emissions have increased at a CAGR of 2.26%.

Table 5: Trends of CH_4 and N_2O emissions from Domestic Wastewater in India

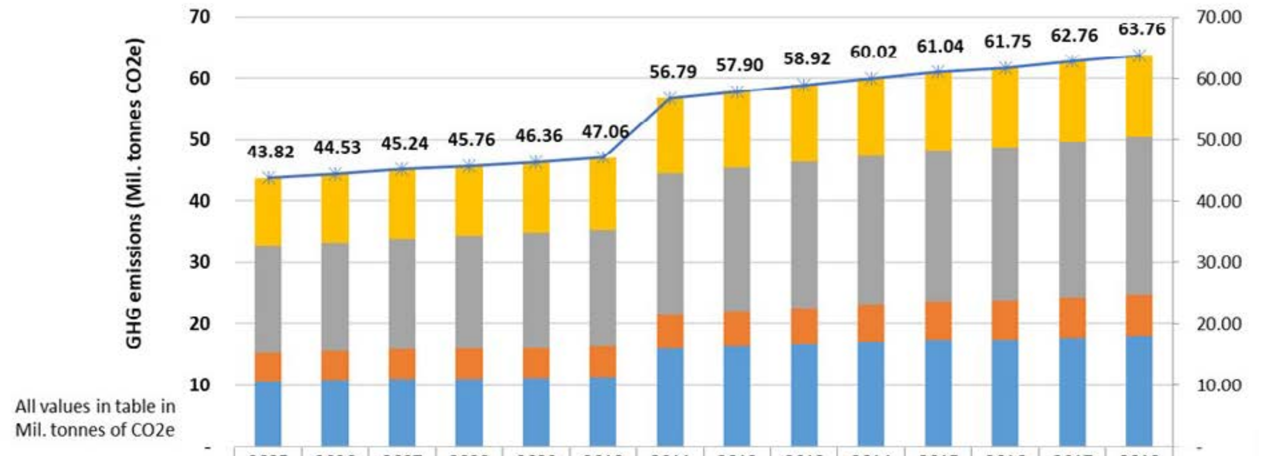
GHG emissions from domestic waste water	GHG emission Mil. tonnes CO_2e				CAGR
	2005	2008	2013	2018	
Domestic waste water (Rural)	28.57	29.80	36.35	39.07	2.26%
Domestic waste water (Urban)	15.25	15.95	22.56	24.68	3.50%
Total	**43.82**	**45.75**	**58.92**	**63.75**	**2.71%**

Source: GHG Platform India, 2022. Waste Sector GHG Emissions

CH_4 is the dominant component of domestic wastewater related GHG emissions in India, accounting for 69% of total domestic wastewater emissions as of 2018 (see Figure 6). Key observations on emissions trends from domestic wastewater are:

- Incremental growth observed in overall GHG emissions.
- The growth trend of CH_4 emissions from urban wastewater and N_2O from both urban and rural areas is relatively high. This can be attributed to:
  - Growing population
  - Urbanization
  - N_2O emissions are dependent on the human protein consumption and the size of urban population consuming protein. With steadily rising nutritional intake of protein and the increase in urban and rural populations over the years, N_2O emissions have increased across India from 2005 to 2018.
  - CH_4 emissions are dependent on the volume of wastewater generation, which is influenced by population and by how wastewater from households is conveyed and treated. Thereby, wastewater management and its incumbent gaps, discussed in previous sections, influence CH_4 emissions from wastewater. N_2O emissions from wastewater are not necessarily impacted by improvements in wastewater treatment.

Consequently, the analysis in the following sections focuses on CH_4 emissions from urban domestic wastewater.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
N2O emission (Rural)	11.09	11.22	11.35	11.49	11.60	11.73	12.17	12.33	12.49	12.64	12.81	12.96	13.12	13.28
CH4 emission (Rural)	17.49	17.76	18.04	18.31	18.59	18.86	23.06	23.46	23.87	24.19	24.59	24.99	25.40	25.80
N2O emission (Urban)	4.57	4.70	4.83	4.96	5.01	5.14	5.45	5.63	5.81	5.99	6.17	6.34	6.51	6.67
CH4 emission (Urban)	10.68	10.85	11.01	11.00	11.16	11.32	16.11	16.48	16.76	17.19	17.47	17.46	17.73	18.01
Total	43.82	44.53	45.24	45.76	46.36	47.06	56.79	57.90	58.92	60.02	61.04	61.75	62.76	63.76

Source: Author's analysis of data from GHG Platform India, 2022. Waste Sector GHG Emissions

Figure 6: Trend of aggregate GHG emissions from domestic wastewater, 2005 - 2018

7.2. Trends and Insights of CH_4 emissions from urban domestic wastewater in top five emitting states

The five states of Maharashtra, Uttar Pradesh, Tamil Nadu, West Bengal, and Gujarat contributed to about 47% of the total CH_4 emissions from urban domestic wastewater in 2018 (see Figure 7). These states also rank high in terms of population size and since the volume of wastewater generated is directly dependent on the size of the population, their associated GHG emissions from domestic wastewater are also higher.

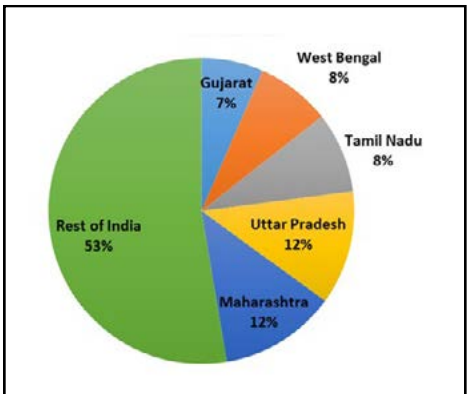


Figure 7: Share of GHG emissions from urban domestic wastewater in top five states, 2018

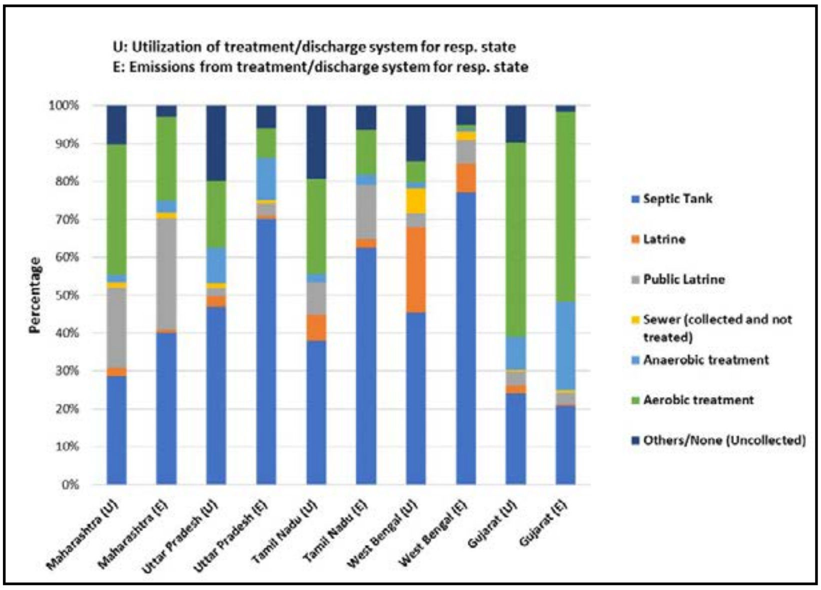


Figure 8: CH_4 emissions and utilization of different treatment/discharge systems for urban areas in top five emitting states, 2018

To better understand trends and drivers of emissions in urban areas, GHG emissions from urban domestic wastewater in the top five emitting states have been further assessed. Key observations and insights include:

- Wastewater treatment/discharge pathways or systems are broadly classified by the 2006 IPCC Guidelines into collected systems (i.e. wherein wastewater is conveyed using a sewer network) and uncollected systems (wastewater not conveyed using a sewer network and handled through on-site sanitation systems). The four states of Maharashtra, Uttar Pradesh, Tamil Nadu, and West Bengal have relatively lower proportions of population connected to sewer network and are thereby primarily dependent on on-site sanitation systems such as septic tanks, household toilets, pit latrines, and public toilets. Such on-site sanitation systems are major sources of CH_4 emissions in the four states of Waste Bengal, Tamil Nadu, Uttar Pradesh and Maharashtra.
- Emissions from septic tanks range from 21% to 77% across the top five emitting states in 2018. These emissions are correlated to significant utilization (i.e. the proportion of population using a certain treatment system) reported for septic tanks in these five states, ranging from 24% to 47% (see Figure 8). Septic tanks are on-site treatment systems having a relatively higher CH_4 emission generation potential (methane correction factor value of 0.5[3]) and thereby contribute significantly to emissions from urban domestic wastewater. Connecting septic tanks with the sewer network and treating the wastewater aerobically downstream in well-managed treatment plants can reduce emissions.
- Aerobic treatment systems and latrines are the second and third-highest contributors to the total CH_4 emissions, on average, across the top five emitting states. Public latrine systems have a relatively high methane correction factor value of 0.5 and therefore are a key contributor to CH_4 emissions. CH_4 emissions from aerobic treatment systems are high since the existing aerobic treatment based STPs in the country often operate sub-optimally and are not well managed. The methane correction factor value for 'not well-managed aerobic systems' is 0.3 as against a 'methane correction factor' value of 0 (and therefore no CH_4 emission) for 'well-managed aerobic treatment systems'. Therefore, it is important to manage aerobic treatment systems effectively. Further, some portion of urban wastewater that is collected through the sewer network is not treated downstream (i.e. sewer - collected & not treated category) due to insufficient installed capacity and operational inefficiencies of STPs. Such wastewater that is collected through sewer systems but does not flow to a STP usually stagnates and leads to CH_4 emission.
- Maharashtra is the largest contributing state to urban domestic wastewater related CH_4 emissions in the country, with emissions driven by prevalence on uncollected on-site sanitation systems. About 37% of the households are connected to the sewer network and the remaining household wastewater is managed through on-site sanitation systems. About 3% of the wastewater collected through the sewer network is not treated.
- In the case of Tamil Nadu and Uttar Pradesh, less than 20% of households are connected to sewer network, with the rest are dependent on on-site sanitation systems. About 5% of the wastewater collected through the sewer network in Uttar Pradesh is not treated.
- In West Bengal, more than 90% of the emissions are attributed to on-site sanitation systems such as septic tanks, pit latrines and toilets, with about 86% of households reliant on such systems. About 13% of households are connected to sewer network, out of which about 49% i.e. almost half of the wastewater collected through the sewer network does not flow into a STP as of 2020. Such wastewater, that is ultimately not treated, stagnates and leads to CH_4 emissions.
- Gujarat has relatively lower CH_4 emissions among the top five emitting states. A contributing reason is that a higher portion of Gujarat's domestic wastewater is treated in STPs as compared to the other four states. However, it ranks in the top five emitting states due to the size of its population and prevalent inadequate operations and management of aerobic treatment facilities. As per CPCB report 2019, there is gap of 20% in the wastewater treatment capacity due to non-utilization and under-utilization of installed capacity of Gujarat's wastewater treatment facilities.

3 MCF values indicated in Table 38 of this note and based on the 2006 IPCC Guidelines, Vol.5, Chapter 6 - Wastewater treatment and discharge, Table 6.3. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

8. ANALYSIS OF GHG EMISSION REDUCTION POTENTIAL FROM URBAN DOMESTIC WASTEWATER TREATMENT

Urban areas across Indian states are undergoing significant growth and population increase, leading to higher volume of wastewater generation and resulting GHG emissions. Significant infrastructure development is underway and planned for wastewater management through flagship programs such as AMRUT, State government projects, and other initiatives, particularly for augmenting treatment capacity and network coverage. It is important to assess and analyse the trajectory of GHG emissions from urban wastewater, while identifying potential opportunities for emission reduction offered by the adoption of low-carbon treatment solutions.

This section includes an analysis of the anticipated GHG emissions from urban wastewater and prospective GHG mitigation potential in aerobic and anaerobic treatment facilities. The analysis and inferences are presented using information from the two states of Gujarat and West Bengal, which have the highest and lowest percentages of sewer connectivity respectively among the top five GHG emitting states for urban domestic wastewater. Thereby, these two states appropriately represent a broad spectrum, in terms of existing wastewater management systems, and have been included in the analysis.

The purpose of the analysis is to understand and compare the trajectories of urban wastewater related CH_4 emissions in different scenarios against the business-as-usual scenario. GHG emissions have been modelled for year 2025 and 2030. 100% coverage of sewer network and treatment capacity is assumed for 2025 in both Gujarat and West Bengal, in line with targets outlined in AMRUT 2.0. The scenarios and key considerations in the emission analysis, presented in the following section, are:

Scenarios	Assumptions
Baseline	• Corresponds to GHG emissions as estimated by the GHG Platform India for year 2018 • Existing operational treatment capacities of aerobic and anaerobic technologies in STPs are considered • The technology-wise split/mix of operational STP capacity for Gujarat is 85% aerobic and 15% anaerobic. For West Bengal, aerobic treatment accounts for 94% of existing operational capacity while 6% of STP capacity is of anaerobic treatment type. • To reflect current practices and context, no capture and recovery of CH_4 is considered in anaerobic treatment-based STPs
Business-as-usual (BAU) scenario	• Considers the existing mix or percentage split of aerobic and anaerobic technologies (same as baseline) for both Gujarat and West Bengal. • Volume of wastewater generation is projected for 2025 and 2030 based on urban population projections. STP capacity (cumulative and new/additional) to achieve treatment of 100% of the wastewater generated is correspondingly estimated. • GHG emissions from anaerobic and aerobic treatment have been estimated using the relevant methodology in line with the baseline and corresponding emission factors • No capture and recovery of CH_4 is considered in anaerobic treatment-based STPs
Scenario 1	• Assumes mix or percentage split of STP capacity as 75% aerobic and 25% anaerobic treatment-based for both Gujarat and West Bengal. • Projections of volume of wastewater generation and overall STP capacity (cumulative and new/additional) for 2025 and 2030 are similar to the BAU scenario • Capture and recovery of CH_4 emission is considered for the STP capacity that corresponds to anaerobic treatment

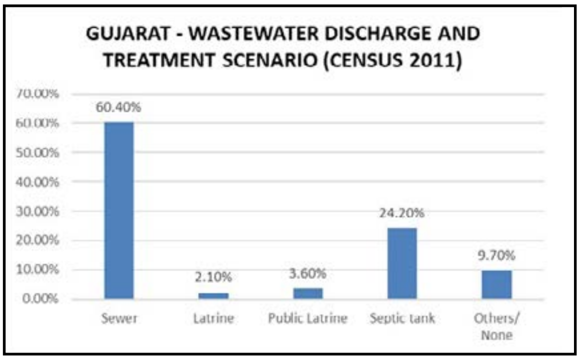
Scenarios	Assumptions
Scenario 2	● Assumes mix or percentage split of STP capacity as 50% aerobic and 50% anaerobic treatment-based for both Gujarat and West Bengal ● Projections of volume of wastewater generation and overall STP capacity (cumulative and new/ additional) for 2025 and 2030 are similar to the BAU scenario ● Capture and recovery of CH_4 emission is considered for the STP capacity that corresponds to anaerobic treatment
Scenario 3	● Assumes mix or percentage split of STP capacity as 25% aerobic and 75% anaerobic treatment-based for both Gujarat and West Bengal ● Projections of volume of wastewater generation and overall STP capacity (cumulative and new/ additional) for 2025 and 2030 are similar to the BAU scenario ● Capture and recovery of CH_4 emission is considered for the STP capacity that corresponds to anaerobic treatment
Other assumptions	● In the analysis, the potential reduction of GHG emissions due to CH_4 recovery is calculated considering 100% recovery from the total capacity of anaerobic treatment systems, corresponding to each scenario that is mentioned. It is to be noted that 100% recovery of CH_4 is an ideal situation and actual CH_4 recovery rates realized on- ground can be lower and should be appropriately factored in. ● The GHG emissions considered reflect CH_4 emissions from treatment and discharge of urban domestic wastewater in anaerobic and aerobic treatment systems. Energy-related GHG emissions and emission reduction resulting from offset of conventional energy due to use of bio-energy generated from CH_4 capture are not included in the analysis.

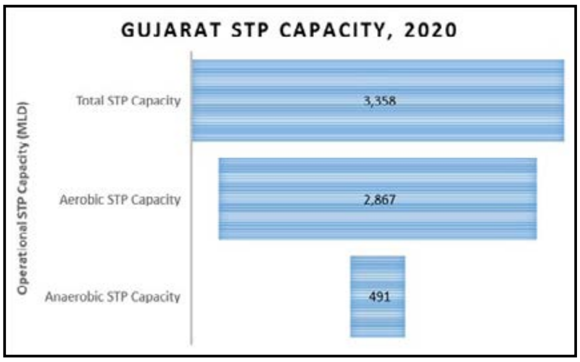
Gujarat: Potential Impact on Emissions from Adoption of Wastewater Treatment Technologies

State profile

Baseline	2018
Urban population (est.) (million)	32.23
Operational STP capacity (aerobic treatment type)	85%
Operational STP capacity (aerobic treatment type)	15%
Baseline GHG emissions from urban wastewater (million tCO_2e) (GHGPI estimate)	1.21

Projection	2025	2030
Estimated urban population (million)	38.72	43.35
Estimated total urban wastewater generation (MLD)	5,695	6,376
New STP capacity required to achieve 100% treatment (MLD)	2,337	3,018





Anaerobic and Aerobic Treatment: GHG Emission Reduction Potential

Year	2018	2025				2030			
Scenarios	**Baseline:**	**Business-as-usual**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Business-as-usual**	**Scenario 1**	**Scenario 2**	**Scenario 3**
STP capacity mix	85% Aerobic & 15% Anaerobic (no CH_4 recovery)	85% Aerobic & 15% Anaerobic (no CH_4 recovery)	75% Aerobic & 25% Anaerobic (with CH_4 recovery)	50% Aerobic & 50% Anaerobic (with CH_4 recovery)	25% Aerobic & 75% Anaerobic (with CH_4 recovery)	85% Aerobic & 15% Anaerobic (no CH_4 recovery)	75% Aerobic & 25% Anaerobic (with CH_4 recovery)	50% Aerobic & 50% Anaerobic (with CH_4 recovery)	25% Aerobic & 75% Anaerobic (with CH_4 recovery)
GHG emissions from discharge & treatment of urban wastewater	**Emissions in 2018**	**Emissions in 2025**				**Emissions in 2030**			
Direct emissions (million tCO_2e)	1.21	1.51	0.97	0.85	0.73	1.69	1.08	0.93	0.77
Absolute change in emissions from 2018 Baseline (million tCO_2e)	-	+ 0.30	- 0.23	- 0.35	- 0.48	- 0.48	- 0.12	- 0.28	- 0.44
Percent change in emissions compared to 2018 Baseline	**-**	**+ 25%**	**- 19%**	**- 29%**	**- 40%**	**+ 40%**	**- 10%**	**- 23%**	**- 37%**

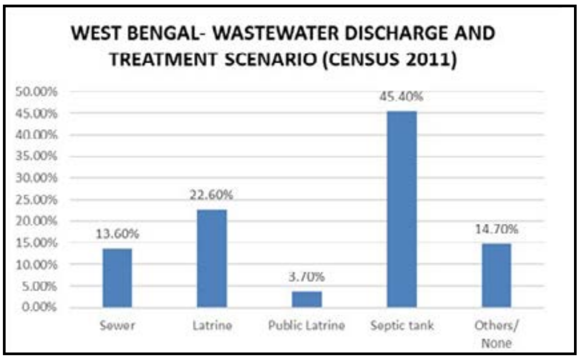
Note: For calculation of direct emissions in 2025 and 2030, 100% recovery of methane has been considered from installed capacity of new anaerobic STPs corresponding to the scenarios

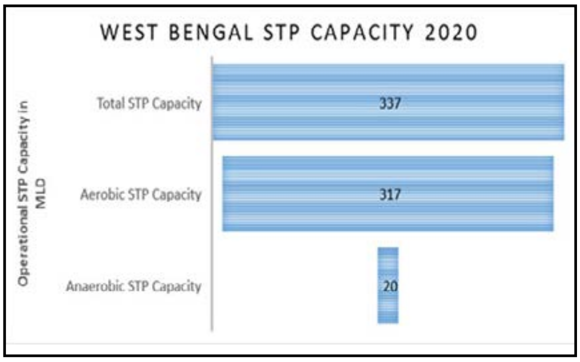
West Bengal: Potential Impact on Emissions from Adoption of Wastewater Treatment Technologies

State profile

Baseline	**2018**
Urban population (est.) (million)	35.15
Operational STP capacity (aerobic treatment type)	94%
Operational STP capacity (aerobic treatment type)	6%
Baseline GHG emissions from urban wastewater (million tCO_2e) (GHGPI estimate)	1.46

Projection	**2025**	**2030**
Estimated urban population (million)	41.20	45.52
Estimated total urban wastewater generation (MLD)	6,097	6,737
New STP capacity required to achieve 100% treatment (MLD)	5,760	6,400





Anaerobic and Aerobic Treatment: GHG Emission Reduction Potential

Year	2018	2025				2030			
Scenarios	**Baseline:**	**Business-as-usual**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Business-as-usual**	**Scenario 1**	**Scenario 2**	**Scenario 3**
STP capacity mix	85% Aerobic & 15% Anaerobic (no CH_4 recovery)	85% Aerobic & 15% Anaerobic (no CH_4 recovery)	75% Aerobic & 25% Anaerobic (with CH_4 recovery)	50% Aerobic & 50% Anaerobic (with CH_4 recovery)	25% Aerobic & 75% Anaerobic (with CH_4 recovery)	85% Aerobic & 15% Anaerobic (no CH_4 recovery)	75% Aerobic & 25% Anaerobic (with CH_4 recovery)	50% Aerobic & 50% Anaerobic (with CH_4 recovery)	25% Aerobic & 75% Anaerobic (with CH_4 recovery)
GHG emissions from discharge & treatment of urban wastewater	**Emissions in 2018**	**Emissions in 2025**				**Emissions in 2030**			
Direct emissions (million tCO_2e)	1.46	0.48	0.24	0.17	0.09	0.53	0.26	0.18	0.10
Absolute change in emissions from 2018 baseline (tCO_2e)	-	- 974,653	-1,215,618	-1,290,079	-1,364,540	-924,204	-1,190,805	-1,273,537	-1,356,269
Percent change in emissions compared to Baseline 2018	**-**	**- 67%**	**-84%**	**-89%**	**-94%**	**-64%**	**-82%**	**-88%**	**-93%**

Note: For calculation of direct emissions in 2025 and 2030, 100% recovery of methane has been considered from installed capacity of new anaerobic STPs corresponding to the scenarios.

Key findings and observations from the analysis for year 2025

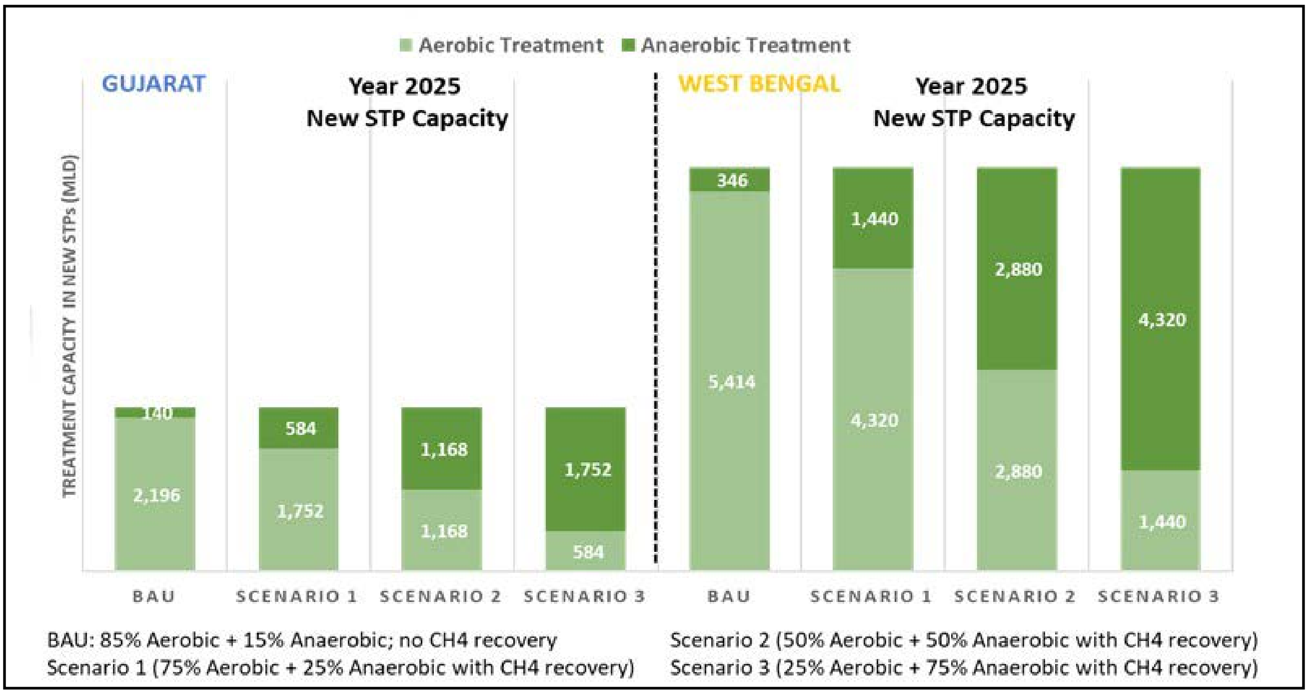


Figure 9: Anaerobic and Aerobic treatment capacity for different scenarios of treatment technology mix in new STPs, 2025

Gujarat

Baseline

- Sewer coverage and treatment capacity (2020): 60%
- STP capacity mix: 85% aerobic treatment & 15% anaerobic treatment. No CH_4 recovery

BAU 2025

- 100% coverage by 2025: new STPs of 2,337 MLD required (1.7 times increase from 2020)
- Treatment capacity: 3,358 MLD in baseline to 5,695 MLD in 2025
- BAU Scenario (2025): 25% increase in GHG emission from 2018 (+0.3 million tCO_2e)

Intervention for GHG reduction in Scenarios 1,2 and 3

- With higher proportion of anaerobic STPs with CH_4 recovery, results in corresponding additional GHG emission reduction
- GHG emission reduction from baseline: 19% (scenario 1) to 40% (scenario 3)
- Absolute GHG emission reduction from baseline: 0.23 $MtCO_2e$ (scenario 1) to 0.47 $MtCO_2e$ (scenario 3)
- Significant emissions from aerobic treatment-based STPs already in place

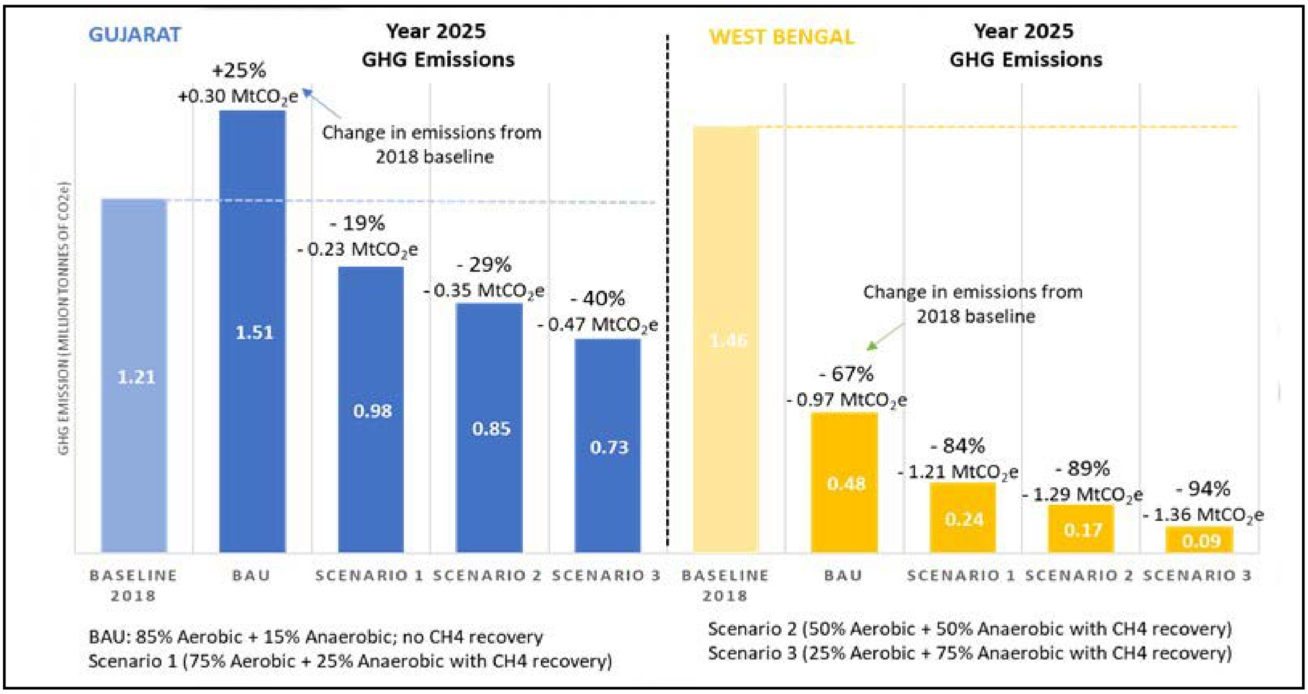


Figure 10: GHG emissions for different scenarios of treatment technology mix in new STPs, 2025

West Bengal

Baseline

- Sewer coverage and treatment capacity (2020): 13.6%
- STP capacity mix: 94% aerobic treatment & 6% anaerobic treatment. No CH_4 recovery

BAU 2025

- 100% coverage by 2025: new STPs of 5,760 MLD required (15 times increase from 2020)
- Treatment capacity: 337 MLD in baseline to 5,760 MLD in 2025
- BAU Scenario (2025): 67% decrease in GHG emission from 2018 (-0.97 million tCO_2e)

Intervention for GHG reduction in Scenarios 1,2 and 3

- With higher proportion of anaerobic STPs with CH_4 recovery, results in corresponding additional GHG emission reduction
- GHG emission reduction from baseline: 84% (scenario 1) to 94% (scenario 3)
- Absolute GHG emission reduction from baseline: 1.21 $MtCO_2e$ (scenario 1) to 1.36 $MtCO_2e$ (scenario 3)
- In large-scale treatment capacity augmentation, deep emission reduction can be realized with higher adoption of anaerobic technologies with CH_4 recovery

8.1. Key Inferences from GHG emission analysis for Gujarat and West Bengal

Achieving 100% methane recovery from existing and upcoming anaerobic treatment capacity should be a key state-level target in urban wastewater management: About 30% of CH_4 generated in anaerobic STPs is lost as dissolved gas in the treated effluent.[4] Thereby, anaerobic wastewater treatment systems offer opportunities for CH_4 capture and its recovery to generate biogas-based energy that can be used on-site to offset the use of conventional GHG emitting energy sources. Anaerobic treatment technologies such as sequential batch reactor, when integrated with CH_4 recovery systems to be used for energy generation, offer higher emission reduction along with co-benefits such as lower operational energy. Therefore, anaerobic treatment solutions clubbed with CH_4 recovery systems should be preferred in the deployment of new infrastructure for wastewater treatment. CH_4 recovery systems should also be integrated into existing anaerobic treatment-based STPs to the extent possible.

Adoption of anaerobic technologies with CH_4 capture and recovery systems should be prioritized and targeted in all new STPs for higher GHG emission reduction: It is found that a higher mix of CH_4 recovery based anaerobic solutions in wastewater treatment infrastructure will lead to corresponding higher reduction in GHG emissions. As the capacity of anaerobic solutions with CH_4 recovery goes higher, a correspondingly higher volume of domestic wastewater will undergo anaerobic treatment, and thereby potential for GHG emission reduction potential will increase. This is evident when comparing potential GHG emission reduction in scenario 1 (with 25% of new STP capacity as anaerobic) against that in scenario 3 (with 75% of new STP capacity as anaerobic) for Gujarat and West Bengal. States can prioritize installation of anaerobic technologies (equipped with appropriate CH_4 capture and recovery systems) in at least 50% of new STP capacity, to effectively tap into GHG emission reduction potential of new wastewater treatment infrastructure.

Low existing wastewater treatment capacities in states offers opportunities to achieve deep emission reduction by opting for predominant scale-up of anaerobic treatment facilities with CH_4 recovery: For states that have low existing sewer network connectivity and wastewater treatment capacity and are highly dependent on on-site sanitation systems, large-scale augmentation of centralized wastewater network and treatment offers opportunities for significant GHG emission reduction. Placing emphasis on higher adoption of anaerobic treatment with CH_4 recovery in such states can help achieve deep emission reduction, as seen in the case of West Bengal, wherein emissions can be reduced by as much as 94% by 2025 if 75% of new STP capacity is of anaerobic type with CH_4 recovery.

In States with significant wastewater treatment capacity already in place, adoption of CH_4 recovery based anaerobic treatment solutions will need to be supported with better management of existing aerobic STPs: For states with a fair degree of existing of sewer coverage and treatment capacity already in place, GHG emissions can be cut down by opting for anaerobic technologies with CH_4 recovery in new wastewater treatment infrastructure. However, this strategy alone is unable to achieve deep emission reduction since the aerobic STPs that are already in place remain a key contributor to GHG emissions. This can be seen in the case of Gujarat, wherein GHG emissions to the tune of 0.73 million tCO_2e still exist in scenario 3, even if 75% of new STP capacity is using anaerobic technology with CH_4 recovery systems. Thereby, additional interventions that target efficient operation and improved performance in existing and new aerobic treatment-based STPs are recommended in order to lower their emission generation potential. The MCF value (i.e. emission generation potential) for 'not well -managed aerobic systems' is 0.3 as against MCF value of 0 (and therefore no CH_4 emissions) for 'well -managed aerobic treatment systems'. This finding further highlights the need for states that are planning for large-scale wastewater infrastructure development to prioritize integration of low-carbon CH_4 recovery based anaerobic solutions and thereby avoid potential lock-in of carbon intensive infrastructure.

4 Global Methane Initiative (2013): Municipal Wastewater Methane: Reducing Emissions, Advancing Recovery and Use Opportunities. Accessed August 2022. Available at: https://www.global-methane.org/documents/ww_fs_eng.pdf

9. RECOMMENDATIONS FOR MITIGATION OF GHG EMISSIONS FROM URBAN DOMESTIC WASTEWATER

Considering the current status of wastewater management along with associated GHG emission trends, key action areas and recommendations identified for the mitigation of GHG emissions from urban domestic wastewater include:

Augment wastewater treatment infrastructure by prioritizing anaerobic treatment technologies to tap into opportunities for methane recovery and deep GHG emission reduction: CH_4 recovery from wastewater is a key factor for effective reduction of GHG emissions. With flagship national programs such as AMRUT 2.0 aiming for 100% wastewater treatment by 2025-26, significant new centralized treatment systems will be deployed across states. The creation of such large-scale wastewater management infrastructure needs to be channelized towards and integrated with national and state-level GHG emission reduction targets, in order to inform decision-making and have future development inclined towards adoption of low-carbon anaerobic treatment systems. As noted in earlier sections, prioritizing uptake of CH_4 recovery based anaerobic treatment will lead to significant GHG emission reduction. This strategy can help realize GHG mitigation potential that exists, particularly in states with low existing coverage of sewer network and wastewater treatment infrastructure.

Better management of existing aerobic STPs is necessary to reduce emissions: Targeting GHG emission reduction in aerobic STPs is necessary in states that have significant aerobic treatment infrastructure already in place. Interventions such as effective performance management through integration of IT systems, improving aeration efficiency, and adoption of energy-efficient measures can help reduce GHG emissions from aerobic systems. Moreover, such actions can prevent stagnation of untreated wastewater and help increase the quantity of treated wastewater, leading to improvements in service delivery.

Expanding sewerage network in sync with augmentation of treatment capacity: With coverage of the existing sewer network standing at 60% in urban areas, expansion of piped sewer network to achieve 100% coverage should be prioritized. Having adequate piped network in place will ensure that the generated wastewater reaches treatment plants and that GHG mitigation potential is optimally realized. Augmentation of sewage network expansion in tandem with treatment capacity augmentation, both spatially and time-wise, is a key enabling action to achieve GHG emission reduction.

Decentralized wastewater treatment solutions to complement time-taking large-scale infrastructure development: For states with large gaps in wastewater management and pre-dominance of on-site sanitation systems such as septic tanks and latrines, expansion of sewer network and centralized treatment capacity is expected to take a long time and happen in a phased-manner. It is recommended that states such as West Bengal, in need of large-scale improvements in wastewater management and infrastructure, include faecal sludge management and septage treatment systems as well as decentralized wastewater management solutions into their long-term sanitation strategies and plans. It is important to prioritize connecting households using septic tanks to the sewerage network, wherever expansion is taking place and funds are available. Opting for improved decentralized wastewater treatment systems (DEWATs) over conventional on-site septic tank systems offers opportunities to reduce GHG emissions. DEWATs that enable reuse of treated wastewater and have relatively low energy consumption can be adopted in small and medium-scale towns (see Annexure 2 for further information on DEWATs)

The following considerations need to be additionally taken into account:

Treatment of sludge and sustainable by-products: Significant amount of sludge is generated from the treatment of wastewater in existing STPs. Limited data is available at present on the treatment of such digester sludge. As per CPCB norms for sludge treatment, dewatering of sludge should be carried out using thickener followed by filter press or centrifuge or an equivalent mechanical device. Sludge drying beds are provided for emergency use only. The compressed sludge should be converted into good quality manure through composting or vermi-composting processes. Sludge combustion with electricity generation is a recent solution that is available. These opportunities need to be explored and validated further.

Recycling and reuse of treated wastewater: Re-use of treated wastewater can help in conservation of freshwater and groundwater resource. Various ULBs and concerned authorities have focused on the reuse of treated wastewater in horticulture, irrigation, non-contact impoundments and washing, and in industrial activities. The Central Public Health and Environmental Engineering Organisation (CPHEEO) has prescribed standards for reuse of treated wastewater for different purposes. Case studies on recycling, reuse and energy recovery from treated wastewater are provided in Annexure 3.

Strengthening capacities of decision-makers and stakeholders: Development, implementation and enforcement of wastewater management systems involves a wide range of public and private sector stakeholders at the state and city level. Therefore, strengthening local institutional and administrative capacity is crucial. Raising awareness, building technical capacities, and offering strategic guidance to key decision-makers, actors and stakeholders is necessary to drive wide-scale transition to low-carbon sanitation.

Scaling up anaerobic treatment technologies in urban areas is essential due to its potential for methane recovery and additional advantages such as lower sludge yield, lesser land requirement, and relatively lower capital and operational costs. Further assessment of different anaerobic and aerobic treatment technologies with regard to GHG emission reduction, various benefits and viability is important. Such information can help to better inform decision-making, promotion of appropriate solutions in national and state sanitation planning frameworks, and adoption on-ground in urban areas.

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ANNEXURE 1: STATUS OF DEPLOYMENT OF AEROBIC AND ANAEROBIC WASTEWATER TREATMENT TECHNOLOGIES IN STPS

#	Process/ Method	Technology	Installed Capacity in MLD	Number of STPs
1	Aerobic	Activated Sludge Process (ASP)	9,486	321
2		Extended Aeration (EA)	474	30
3		Sequencing Batch Reactors (SBR)	10,638	490
4		Moving Bed Biofilm Reactor (MBBR)	2,032	201
5		Fluidised Aerobic Bed Reactor (FAB)	242	21
6		Oxidation Pond (OP)	460	61
7		Others - Aerated Lagoon (AL), Trickling Filter (TF), Bio-Tower, Electro Coagulation (EC), MBR, FMBR and Root Zone etc	8,497	364
Sub -Total A			31,829 (88% of total)	1488 (91.2% of total)
8	Anaerobic	Up flow Anaerobic Sludge Blanket (UASB)	3,562	76
9		Waste Stabilisation Pond (WSP)	789	67
Sub- Total B			4,351 (12% of total)	143 (8.7% of total)
Total			**36,180**	**1631**

Source: Central Pollution Control Board (CPCB), March 2021

ANNEXURE 2: OVERVIEW AND COMPARISON OF LOW-ENERGY DECENTRALIZED WASTEWATER TREATMENT TECHNOLOGIES

Name of the technology	Treatment method	Treatment capacity	Treated water reuse	Capital cost (Rs/ KLD)	O&M cost (Rs/ KLD/year)
Soil biotechnology	Sedimentation, filtration, and biochemical process	5KLD–3.3 MLD	Horticulture and cooling systems	10,000–15,000	1,000–1,500
Soil-scape filter	Filtration through biologically-activated medium	1–250 KLD	Horticulture	20,000–30,000	1,800–2,000
DWWTs	Sedimentation, anaerobic treatment, plant root zone treatment, and oxidation process	Should be more than 1 KLD, but plants bigger than 1 MLD are not feasible as would need extensive land area	Horticulture, mopping floors, cooling towers and flushing	35,000–70,000	1,000–2,000
Eco sanitation, zero discharge toilets	Separation of faecal matter and urine	Individual and community toilets together depending upon number of users	Flushing, horticulture, composting	30,000–35,000 (includes civil work)	35,000– 40,000 (includes salary of the caretaker)
Fixed film bio-filter technology (FFBT)	Settling and flow equalisation followed by enhanced natural degradation (biochemical process)	0.5 KLD to 1 MLD	Horticulture, car washing	25,000–35,000	0 1,000–2,000
Phytorid	Settling followed by plan root zone treatment in specially engineered baffled treatment cells which provides both aerobic and anaerobic treatment	5 KLD–1 MLD	Horticulture	14,000–35,000	1,000–2,000

ANNEXURE 3: CASE STUDIES ON WASTEWATER REUSE, RECYCLING AND ENERGY RECOVERY IN INDIA

1. Delhi - Energy recovery from wastewater treatment plant

Delhi has started recycling and reusing water and treated wastewater due to rapidly diminishing groundwater levels. Currently, about 630 million litres per day (MLD) are being reused in power plants and horticulture. All government buildings must now use only recycled water for all non-drinking water purposes and the construction industry is required to use only treated wastewater as well, but the latter measure is only working to a very limited extent so far. The Pragati power plant runs exclusively on treated wastewater from the Delhi Gate sewage treatment plant because groundwater levels are now too low. The Nilothi WWTP (90 MLD capacity) in West Delhi built by the company Veolia uses conventional biological treatment processes for the sewage, covering 50% of its electricity needs through biogas production, but more advanced technologies to reduce the amount of sludge. The remaining sludge will be sold as manure to farmers at a low price. The reuse of wastewater and sludge in agriculture is somewhat difficult to organize in Delhi as there are hardly any farmers left in peri-urban areas.

The Delhi Water Policy of 2015 (draft) outlines elements of a future approach to water management that rests on five pillars: demand management; optimization of available resources; equity; augmentation of internal resources; and building resilience. The draft policy recognizes that a paradigm shift is required, namely one that sees sewage as a resource and reduces the energy and land footprints of wastewater systems, promotes recycling and reuse of water as well as decentralized treatment and alternative treatments systems. There are policy targets to increase wastewater reuse to 25% by 2017, 50% by 2022 and 80% by 2027. Decentralized treatment of wastewater will be promoted, alternative treatment systems will be encouraged and the decrease the energy footprint of Delhi's entire cycle of water operations (treatment, supply, sewage collection and treatment) is envisioned in the new policy. This indicates that, at the general planning level, some awareness of the water-energy-land nexus and the importance of lifecycle-oriented solutions including decentralized wastewater treatment exist. The success of concretization of this policy into action, including step-wise regulation, planning and implementation remains to be seen.

2. Waste-to-energy plant in Nashik

This innovative waste-to-energy plant will consume both solid waste and 'black' water, making it the first of its kind in India. It will take 10-15 tonnes of food and vegetable waste from 1,300 restaurants and hotels daily, as well as 10-20 tonnes of black water collected from about 400 community toilets in Nashik. Through combined-heat-and power production, the plant is expected to yield 21,000 cubic meters of biogas every day that will convert to up to 32,000 kWh of electricity. Any excess electricity not used by the plant itself will be fed into the power grid under the Maharastra feed-in tariff. The compost the plant generates will be sold to farmers at a low price. Concessions for the constructions of the plant have been awarded; construction is expected to start in 2016. The only two other waste-to-energy plants in India are in Delhi, but they only process solid waste and have been highly criticized for their low-end technology, polluting adjacent neighbourhoods with unhealthy fumes. The Nashik plant will be situated next to the existing municipal waste plant and will use higher-level filters. The Indian government plans to expand waste-to-energy plants across the country. Source: GIZ Factsheet Nashik (2014)

3. Septage pilot project Kochi

This pilot project shows what an innovative, sustainable septage management concept for the city of Kochi could look like, taking into account the high groundwater table and the narrow roads inhibiting traditional sewerage system construction. Drawing on data from a newly developed discharge register in a poor urban area of Kochi, this pilot project seeks to establish a decentralized septage and wastewater treatment system. 'Grey' water from kitchens and bathrooms and 'black' water from toilets will be kept separate (as is already the case in the area). The grey water will go to the collection point, then on to a wastewater treatment plant. These pipes are at a shallower depth than conventional systems, making them apt for Kochi. Black water will be collected on-site in septage tanks for the solids to settle (dewatering) near the households and the sludge turns into biochar by dewatering the septage. The highly concentrated black water effluent will flow into a small, solid-free sewer system that will be treated in a nearby compact sewage treatment plant, thus saving scarce land. The biochar can be used by farmers as fertilizer or for biogas production. In the blueprint design by Hamburg Water, anaerobic treatment of black water and other biomass on-site enables direct heat and power production for the households. However this system is currently not cost-competitive in Kochi and has therefore not been implemented. This pilot project is currently being constructed.

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