



National Level Greenhouse Gas Estimates for the Waste Sector
2005-2013



Credits and Acknowledgements

This methodology note includes an estimation and analysis of India's national-level Greenhouse Gas (GHG) emissions for the Waste Sector, prepared by ICLEI South Asia under the GHG Platform India initiative. The GHG Platform India is a collective civil society initiative providing an independent estimation and analysis of India's GHG emissions across key sectors, namely, Energy, Industry, Agriculture, Livestock, Forestry, and Land-use and Land-use Change, and Waste. The platform seeks to add value to the various ongoing GHG estimation efforts by helping address existing data gaps and data accessibility issues, extending beyond the scope of national inventories, and by increasing the volume of analytics and policy dialogue on India's GHG emission sources, profile, and related policies. The estimates presented in this report have been prepared under the Phase II of the GHG Platform India initiative, wherein the period has been expanded to 2005 – 2013 from 2007 – 2012 in Phase I of the initiative.

The project team would like to thank the Ministry of Environment, Forest and Climate Change for its efforts towards preparation and submission of India's National Communication Reports and the Biennial Update Report, which were invaluable resources that helped in initiating this exercise. We extend our appreciation towards the efforts undertaken by the Ministry of Urban Development, Central Pollution Control Board, various State Pollution Control Boards, and the National Environmental Engineering Research (NEERI) to collate and publish technical information on the Waste sector in India.

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Abbreviations

ASI	Annual Survey of Industries
CO ₂	Carbon dioxide
CO ₂ e	Carbon dioxide equivalent
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CSE	Centre for Science and Environment
CAGR	Compound annual growth rate
CH ₄	Methane
DOC	Degradable organic carbon
FOD	First Order Decay
GDP	Gross Domestic Product
GHG	Greenhouse gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
MCF	Methane Correction Factor
MOSPI	Ministry of Statistics & Programme Implementation
Mil. tonnes	Million tonnes
NEERI	National Environmental Engineering Research Institute
NSSO	National Sample Survey Office
N ₂ O	Nitrous oxide
QA	Quality Assurance
QC	Quality Control
STP	Sewage Treatment Plant
SPCB	State Pollution Control Board
UNFCCC	United Nations Framework Convention on Climate Change

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Document Information

Version	Date	Description
2.2	April 1, 2018	The methodology note has been updated based on the peer review process. The revision includes • Improving the document in general for better readability, understanding and to avoid duplication of messages. • Improving the consistency of citation and referencing throughout the report. • Revising the 'Introduction' section to make it more concise. • Adding additional details for clarity on aspects of qualitative assessment of data and emission factors, recommended improvements for sub-sectors, quality assurance and quality control. • Inclusion of sample calculation for the 3 sub-sectors (solid waste disposal, domestic wastewater treatment and discharge, and industrial wastewater treatment and discharge) in the Annexures to enable readers to better understand computation of emissions. It should be noted that the revision does not lead to any changes in the emission estimates.
2.1	September 28, 2017	The draft version of the updated methodology note includes an estimation and analysis of India's annual national-level GHG emissions for the period 2005-2013 for the Waste Sector, prepared by ICLEI South Asia under the phase-II of the GHG Platform India initiative. The time period for National level estimations in Phase II has been expanded to 2005 – 2013 from 2007 – 2012 in Phase I. The framework of the methodology note has been revised to facilitate improved understanding and transparency with regard to the approach, activity data collection, methodologies, emission factors, gaps, uncertainties and other aspects relating to the emission estimation for the Waste sector.
1.0	July 15, 2017	The initial version of the methodology note that includes an estimation and analysis of India's annual national-level GHG emissions for the period 2007-2012 for the Waste Sector, prepared by ICLEI South Asia under the phase-I of the GHG Platform India initiative (www.ghgplatform-india.org).

Executive Summary

Brief Information on GHG estimates:

The Waste Sector contributes to 3.7% of India's total national-level GHG emission (including land use, land use change and forestry) in 2013 as per estimates prepared by the GHG Platform India¹. The key sources of GHG emission included in the Waste sector emission estimates from 2005 to 2013 are solid waste disposal, domestic wastewater treatment and discharge, and industrial wastewater treatment and discharge. Methane (CH₄) is produced and released into the atmosphere as a by-product of the anaerobic decomposition of solid waste and when domestic and industrial wastewater is treated or disposed anaerobically. Nitrous oxide (N₂O) emissions occur due to the protein content in domestic wastewater.

India's GHG emissions for the Waste sector were estimated to be 89.14 million tonnes (Mil. tonnes) of carbon dioxide equivalent (CO₂e) in the year 2013². This represents an increase of 3.41 Mil. tonnes CO₂e, or 4.0%, on the emissions recorded in 2012, and a cumulative increase of 36% (i.e. 23.5 Mil. tonnes CO₂e) as compared to 2005 levels.

Table 1: GHG emission for Waste sector in India in 2005 and 2013

SECTOR/ SUB-SECTOR	EMISSIONS USING GLOBAL WARMING POTENTIAL VALUES FROM IPCC SECOND ASSESSMENT REPORT ³		EMISSIONS USING GLOBAL WARMING POTENTIAL VALUES FROM IPCC FIFTH ASSESSMENT REPORT ⁴		DEVIATION IN EMISSIONS ESTIMATION BETWEEN 2005 AND 2013	
	2005	2013	2005	2013	USING IPCC SECOND ASSESSMENT REPORT	USING IPCC FIFTH ASSESSMENT REPORT
	MIL. TONNES OF CO ₂ EQ.				PERCENT	
4. Waste	65.62	89.14	80.05	110.17	35.8%	37.6%
4A. Solid Waste Disposal	9.25	14.86	12.33	19.82	60.7%	60.7%
4A2. Unmanaged Waste Disposal Sites	9.25	14.86	12.33	19.82	60.7%	60.7%
4D. Wastewater Treatment and Discharge	56.37	74.28	67.72	90.35	31.8%	33.4%
4D1. Domestic Wastewater Treatment and Discharge	39.04	53.24	44.61	62.30	36.4%	39.6%
4D2. Industrial Wastewater Treatment and Discharge	17.33	21.03	23.10	28.05	21.4%	21.4%

Major Inventory developments and Calculations:

The present Phase II estimates for solid waste disposal prepared under this exercise include CH₄ emissions from municipal solid waste collected and disposed at specific waste disposal sites. Emissions of CH₄ and N₂O gases due to discharge and treatment of domestic wastewater are estimated for both urban and rural areas. 12

¹ Available at <http://www.ghgplatform-india.org/economy-wide-emission-estimates>

² India's Second National Communication Report, 2012 and the Biennial Update Report, 2015 both use 100 year GWP values from the IPCC Second Assessment Report, 1996. To ensure consistency and comparability with the official GHG inventory submissions, the estimates indicated in terms of CO₂e throughout this note, (except for Table 1 and Table 8) are based on the GWP values from the IPCC Second Assessment Report, 1996.

³ 100-year GWP values specified for the 3 GHGs considered for the Waste Sector are CO₂: 1, CH₄: 21, N₂O: 310 as per the IPCC Second Assessment Report, 1996, Technical Summary, Table 4.

Available at https://www.ipcc.ch/ipccreports/sar/wg1/ipcc_sar_wg1_full_report.pdf

⁴ 100-year GWP values specified for the 3 GHGs considered for the Waste Sector are CO₂: 1, CH₄: 28, N₂O: 265 as per the IPCC Fifth Assessment Report, 2014, Climate Change 2014: Synthesis Report, Box 3.2, Table.

Available at https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf

industrial sectors considered in the industrial wastewater estimation include Iron and Steel, Fertilizers, Meat, Sugar, Coffee, Pulp and Paper, Petroleum, Beer, Soft Drinks, Rubber, Dairy, and Tannery sectors.

In terms of improvements and updates to the inventory, the domestic wastewater and industrial wastewater emission estimates for 2007-2012 prepared under phase-I activities of the GHG Platform India have been revisited and have been refined based on updated information on activity data and related parameters.

For industrial wastewater emissions, activity data on industrial production⁵ has been revised for the Sugar, Coffee, Beer, and Soft drink sectors. Since, emissions from industrial wastewater are directly proportional to the industrial production; therefore, this has resulted in emission recalculation for the Sugar, Coffee, Beer, and Soft drink sectors⁶. Updated wastewater generation rates have been used in the Pulp and Paper sector emission calculations to reflect significant reduction achieved in wastewater generation by Pulp and Paper industries in India over the years. Emissions from industrial wastewater are directly proportional to the volume of wastewater that is generated⁵. Thus, the use of updated wastewater generation rates has led to recalculation in emissions for the Pulp & Paper sector⁶. The overall industrial wastewater emission estimates from 2007-2012 due to these recalculations in the Pulp and Paper, Sugar, Coffee, Beer, and Soft drink sectors as compared to the previous estimates prepared under phase-I of the GHG Platform India are indicated in Table 2.

Table 2: Recalculations in Cumulative CH₄ emission from industrial wastewater between 2007 and 2012

YEAR	CH ₄ EMISSION FROM INDUSTRIAL WASTEWATER (MIL. TONNES OF CO ₂ e)		DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES	REASON FOR RECALCULATION IN RELEVANT INDUSTRY SECTORS
	PHASE-I ⁷	PHASE- II		
2007	32.51	16.57	-49.01%	- Sugar, Coffee Beer, Soft Drink: Update in data on 'Industrial production' - Pulp & Paper: Update in data on 'wastewater generation per tonne of product'
2008	36.02	16.21	-55.00%	
2009	49.52	16.01	-67.68%	
2010	48.76	17.84	-63.42%	
2011	58.96	18.62	-68.41%	
2012	54.02	19.20	-64.46%	

Regarding domestic wastewater estimates, the scope of emission estimation in phase- I was limited to domestic wastewater generated in urban areas of the country. Given that it was the first instance of emission estimation under the GHG Platform India, this was done with the considerations of consistency and comparability with the Second National Communication, which also accounts for domestic wastewater emissions from urban areas and does not include rural areas. With improved understanding and experience in emission estimation within the GHG Platform India team, the scope of domestic wastewater estimation in Phase II has been expanded to include GHG emissions generated due to treatment and discharge of domestic wastewater in rural areas of the country. Since domestic wastewater emission is directly dependent on the volume of wastewater generated⁸, which in turn will increase with a larger size of population considered, the inclusion of rural domestic wastewater has led to recalculations in the overall estimates for domestic wastewater (see Table 3).

Table 3: Recalculations in total CH₄ emission from domestic wastewater

Year	TOTAL CH ₄ EMISSION FROM DOMESTIC WASTEWATER (MIL. TONNES OF CO ₂ e)		DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES	REASON FOR RECALCULATION
	PHASE-I	PHASE-II		
2007	12.03	24.33	102.3%	Expansion of emission estimation scope in
2008	12.22	24.76	102.6%	

⁵ See section 3.6.2 for details on methodology and activity data for estimation of emissions from 'Industrial wastewater treatment and discharge'

⁶ See section 3.6.5 for details on sector-wise revised activity data used and recalculations for industrial wastewater related emissions for the relevant industry sectors

⁷ Also available at <http://www.ghgplatform-india.org/waste-sector>

⁸ See section 3.5.2 for details on methodology and activity data for estimation of emissions from 'Domestic wastewater treatment and discharge'

Year	TOTAL CH ₄ EMISSION FROM DOMESTIC WASTEWATER (MIL. TONNES OF CO ₂ e)		DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES	REASON FOR RECALCULATION
	PHASE-I	PHASE-II		
2009	12.41	25.20	103.0%	Phase-II to include emissions from domestic wastewater treatment and discharge in rural areas
2010	12.60	25.64	103.4%	
2011	12.80	33.86	164.6%	
2012	13.02	34.46	164.6%	

Further for the urban domestic wastewater emission estimates in Phase I, population size by income group (urban-low income and urban-high income) was based on tier I default country values for fraction of population in urban high-income group (i.e. 0.06) and urban low-income group (i.e. 0.23) respectively as specified in by the 2006 IPCC Guidelines for National GHG Inventories. India's Second National Communication uses these default values for emission estimation and thereby these values were used in Phase I estimates for consistency and comparability. In the Phase II estimates, country-specific tier 2 data on population distribution available from Census of India 2001 and 2011 has been used instead, since the 2006 IPCC Guidelines for National GHG Inventories⁹ recommend the application of higher tier approaches (i.e. tier 2 as compared to tier 1) in emission estimation for improved accuracy and relevance. The corresponding change in population size has led to recalculation in the emission estimates for urban domestic wastewater (see Table 4).

Table 4: Recalculations in total CH₄ emission from urban domestic wastewater between 2007 to 2012

YEAR	CH ₄ EMISSION FROM URBAN DOMESTIC WASTEWATER (MIL. TONNES OF CH ₄)		DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES	REASON FOR RECALCULATION
	PHASE-I	PHASE- II		
2007	12.03	11.42	-5.1%	Revised fraction of population based on Census 2001 data - • Urban low-income: 0.22 • Urban high-income: 0.06
2008	12.22	11.62	-4.9%	
2009	12.41	11.83	-4.7%	
2010	12.60	12.04	-4.5%	
2011	12.80	13.72	7.2%	Revised fraction of population based on Census 2011 data - • Urban low-income: 0.25 • Urban high-income: 0.06
2012	13.02	13.96	7.2%	

Summary of GHG emission trends:

GHG emissions from the Waste sector have increased at a compound annual growth rate (CAGR) of 3.9% per year for the reporting period of 2005 to 2013.

- Emissions from solid waste disposal have registered the highest CAGR of 6.1% among the 3 sub-sectors.
- GHG emissions from the domestic and industrial wastewater have grown at CAGR of 4.0% and 2.5% respectively on average from 2005 to 2013.

The trend of the overall emission is observed to be quite steady with a relatively higher rise between the year 2010 and 2011 (see **Figure I**), largely due to the corresponding increase in the estimated domestic wastewater emissions.

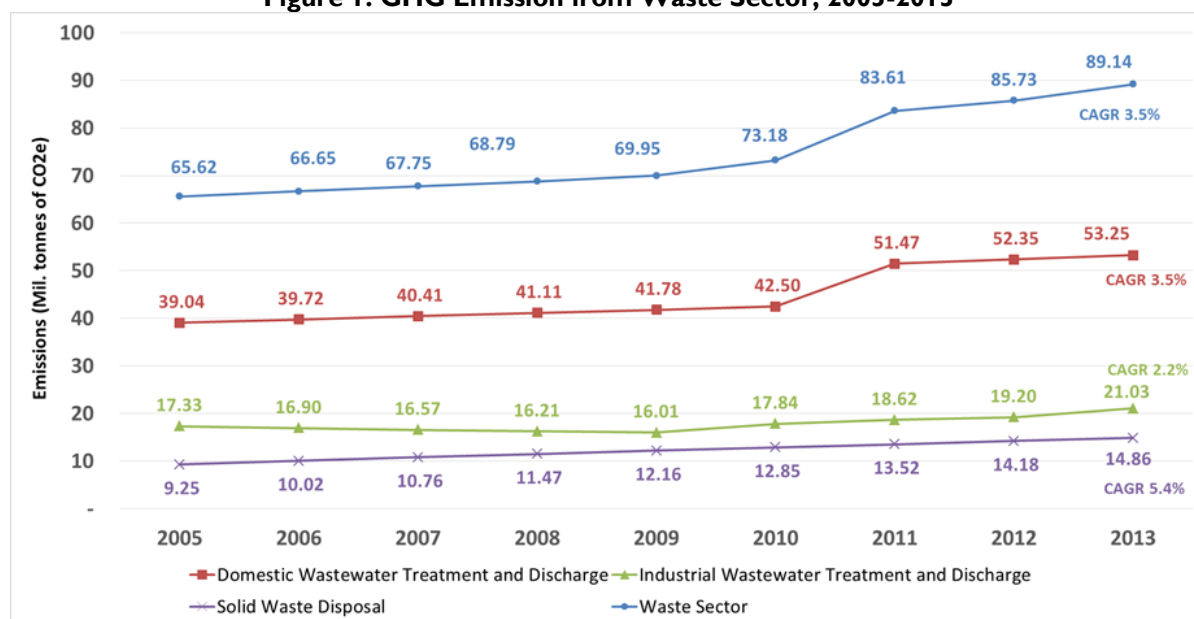
The Waste sector related GHG emission intensity of India's gross domestic product (GDP) is observed to have decreased by 23% in 2013 as compared to the base year of 2005, falling at a CAGR of (-3.2%) per year in the period from 2005 to 2013. Per capita emissions from the Waste sector were seen to rise at a CAGR of 2.1% per annum from 2005 to 2013.

⁹ IPCC Good Practice Guidance and Uncertainty Management in National GHG Inventories, Chapter 7. Available at http://www.ipcc-nggip.iges.or.jp/public/gp/english/7_Methodological.pdf

Highlights on major emitting source categories:

- GHG emissions from treatment and discharge of domestic wastewater treatment and discharge (4D1) have accounted for the highest share in the sector over the reporting period, contributing to nearly 60% of the total emissions in the Waste sector in 2013. Per capita GHG emissions related to domestic wastewater for the urban population were higher by 50% as compared to that for the rural population in 2013.
- Industrial wastewater treatment and discharge (4D2) had the 2nd largest contribution (23.6%) to the Waste sector GHG emissions in 2013, with Pulp and paper, Coffee, Soft drink, Meat and Tannery observed to be critical industries having high specific GHG emission.
- Disposal of solid waste (4A) contributed to 16.7% of the country's total emissions from the Waste sector in 2013, with increased generation and changing waste composition driving the rise in emissions.

Figure I: GHG Emission from Waste Sector, 2005-2013



I Introduction

I.1 Background Information on GHG estimates

GHG Estimates Reporting:

The GHG Platform-India is an Indian Civil Society initiative that aims to provide estimation and analysis of India's GHG emissions across different sectors such as energy, industry, waste and agriculture, livestock, forestry, and land-use and land-use change sectors. The platform's overall objectives are to complement existing efforts of the Indian government, such as the National Communication and Biennial Update Report process of the UNFCCC, by helping address existing data gaps and data accessibility issues, extending beyond the scope of national inventories, and to drive an informed policy dialogue within the country on the GHG emissions inventory and the possibility to reduce emissions in the decades ahead.

The entire exercise of reporting GHG emission estimates from the Waste sector aims to contribute towards analysing and putting together all the existing activity data and emission factors that could be used for Waste sector GHG emission estimations under the GHG Platform India. The various sources used for gathering activity data for estimation, gaps identified in the datasets, and recommendations to improve reliability and accuracy of emission estimation processes have been put forward to the Government of India for further actions.

Greenhouse Gases:

The emission estimation scope covers three GHGs currently: Carbon Dioxide (CO₂), Methane (CH₄), Nitrous Oxide (N₂O). Activities in the Waste sector lead to emission of two GHGs, namely CH₄ and N₂O, both of which are accounted under the estimates. CH₄ is produced and released into the atmosphere as a by-product of the anaerobic decomposition of solid waste and when domestic and industrial wastewater is treated or disposed anaerobically. A smaller amount of N₂O emissions occur from the disposal of domestic wastewater into waterways, lakes, or seas due to the protein content present in domestic wastewater.

Key Source Categories/ Sub-categories:

As per the Intergovernmental Panel on Climate Change (IPCC) reporting structure, the following source categories and sub-categories under the Waste sector have been considered in the emission estimation. The relevant gases considered under each sub –category are also indicated

- 4A Solid Waste Disposal
 - 4A2 Unmanaged Waste Disposal Sites: CH₄
- 4D Wastewater treatment and discharge
 - 4D1 Domestic Wastewater Treatment and Discharge: CH₄ & N₂O
 - 4D2 Industrial Wastewater Treatment and Discharge: CH₄

The source categories and sub-categories considered are in line with India's Second National Communication¹² and the Biennial Update Report 2010¹³.

GHG estimation period

The time period for National level estimations in Phase II has been expanded to 2005 – 2013 from 2007 – 2012 in Phase I. India's Nationally Determined Contribution under the Paris Agreement, 2016 targets reducing the emission intensity of its economy by 33–35% by the year 2030 as compared to that in the base year of 2005¹⁰. Therefore, this emission estimation exercise for the Waste sector has selected the same base year of 2005,

To ensure consistency with India's National Communication Reports and the Biennial Update Report 2010, the emission inventory for all sub-sectors has been prepared on a calendar year basis.

- Activity datasets for industrial production for industrial wastewater emission estimations available on financial year basis have been converted to calendar year datasets for a given calendar year by considering 3/4th of the value from the previous financial year (corresponding to 9 months from April to December out of 12 months in a year) and 1/4th from the next financial year (corresponding to 3 months from January to March out of 12 months in a year). Industrial production data on monthly basis is not available in the datasets used for the industry sectors in this assessment and thereby the above approach is adopted to convert the activity data to calendar year basis.
- For instance, most of the production data for the industry sectors under consideration is available on a financial year basis. 3/4th of the production data from the financial year 2004-05 and 1/4th of the production data from the financial year 2005-06 has been considered and added together to estimate the production data for the calendar year 2005, and so on.

1.2 Institutional Arrangement and Capacity

The GHG India Platform is a collaborative effort of various civil society organizations. The institutional arrangement is given in the figure below.

- The project is funded by Shakti Sustainable Energy Foundation
- Vasudha Foundation holds the secretariat for the platform and is responsible for the GHG emission estimates for AFOLU sector.
- ICLEI – Local Governments for Sustainability, South Asia (ICLEI South Asia) is responsible for GHG emissions estimates for waste sector.

¹⁰ Available at <http://www4.unfccc.int/submissions/INDC/Submission%20Pages/submissions.aspx>

- Center for Study of Science, Technology and Policy (CSTEP) is responsible for GHG emission estimates for energy sector.
- Council on Energy, Environment and Water (CEEW) is responsible for GHG emission estimates for industrial processes and product use sector.
- World Resources Institute India (WRI India) is responsible for peer review of estimations done by all partners previously mentioned.

Figure 2: Institutional Arrangement for GHG Platform - India



ICLEI South Asia works with national and state level governments in different capacities. ICLEI South Asia staff is and has been part of advisory/expert committees for informing policy and decision making at the national and state level (solid waste management, national mission on sustainable habitat, etc.). ICLEI South Asia is nominated as a preferred consultant in delivering services to local authorities by the national government under various schemes such as the SMART CITIES programme (empanelled consultants in 5 states), the Swachh Bharat Mission (national government empanelled consultants and state level committee members and facilitators in Rajasthan), HRIDAY scheme (empanelled city anchors in 3 cities in India), preferred consultants in the Solar City programme of the Ministry of New & Renewable Energy (out of 55 participating cities, ICLEI South Asia has supported the preparation of solar city master plans in 16 cities). ICLEI South Asia has also partnered with various national ministries in rolling out flagship programmes related to waste and sanitation sector such as the Service Level Benchmark programme in Urban Areas (Ministry of Urban Development), the National Urban Sanitation Policy (Ministry of Urban Development), the Swachh Bharat Mission (co-funding in 5 cities in Rajasthan and Maharashtra states).

ICLEI- Local Governments for Sustainability also seeks to build an international policy environment that strengthens local governments and supports local sustainability and climate mitigation. To facilitate this, ICLEI coordinates local government representation in several UN organizations. ICLEI's contributions in the form of side events, publications, verbal interventions, and official background papers have been a consistent, major source of international attention to local initiatives and opportunities to enhance sustainability and mitigate GHG emissions.

The following staff members from ICLEI South Asia's Energy & Climate team, which is engaged in ICLEI's portfolio of energy and climate mitigation projects, have been involved in this assignment:

- Emani Kumar, Deputy Secretary General of ICLEI Global and Executive Director, ICLEI South Asia: Provided strategic inputs towards methodological approach for emission estimation and finalization of the methodology note.
- Soumya Chaturvedula, Deputy Director: Provided expert inputs to steer the process to help prepare and finalize this document including methodological approach, identification of datasets, assumptions to close data gaps, verification and review of datasets and emission estimates for all sub-sectors to help in finalization of this document.
- Nikhil Kolsepatil, Manager- Energy & Climate: Led overall preparation and finalization of this methodology document. Coordinated and led tasks towards methodology preparation and finalization, data identification, collection and estimate preparation, review and finalization of data and inventory estimates.
- Anandhan Subramaniam, Manager- Energy & Climate: Undertook data collection, research, developing methodology for rural and urban domestic wastewater estimates, data validation and

estimate preparation for the domestic wastewater sub-sector and drafted related sections in this note.

- Keshav Jha, Sr. Project Officer - Energy & Climate: Undertook data collection, research, data validation and estimate preparation for the industrial wastewater sub-sector and drafted related sections in this document.
- Sonali Malik, Project Officer - Energy & Climate: Undertook data collection, research, data validation and estimate preparation for the municipal solid waste sub-sector and drafted related sections in this document.

Reviewers' Profile:

Chirag Gajjar:

Chirag Gajjar is senior manager and leads mitigation for WRI's climate program in India. He leads research and project management execution for WRI India. He is the focal point for carbon pricing and science-based targets work in India. He also focuses on GHG measurement and management for businesses, and engaging with policy makers on long-term decarbonization strategies. He has been instrumental in supporting various Indian businesses to adopt internal price on carbon. He is the project leader for WRI India on GHG Platform India project. chirag.gajjar@wri.org

Subrata Chakrabarty:

Subrata Chakrabarty works with WRI's climate program in India. He primarily works on GHG Platform – India (SEEG India Projects) which aims at creating credible and accurate national and state - level GHG inventories based on IPCC methods. His role includes reviewing the GHG estimation reports for various sectors such as energy, waste, IPPU, AFOLU. In addition, he leads the capacity building activities under India GHG Program – a flagship initiative by WRI India, disseminating regional, sectoral and global best practices to create a culture of inventorization and benchmarking of GHG emissions in India. He also supports the team with the need-based work related to Science Based Targets and Internal Carbon Pricing. subrata.chakrabarty@wri.org

1.3 GHG Estimation Preparation, Data Collection, Process and Storage

GHG Estimates preparation:

ICLEI South Asia has estimated the GHG emissions for the Waste Sector based on the 2006 IPCC Guidelines for National GHG Inventories¹¹ with all relevant calculation approaches and default values of activity data and emission factors drawn from the guidelines as applicable. The overall methodology and approach adopted for the Waste Sector is similar to that followed in the phase-I estimates of the GHG Platform India and in line with India's Second National Communication¹² and Biennial Update Report 2010¹³ submitted to the United Nations Framework Convention on Climate Change (UNFCCC). As indicated previously, specific source sub-categories included in the emission estimates are:

- 4A2 Unmanaged Waste Disposal Sites
- 4D1 Domestic Wastewater Treatment and Discharge
- 4D2 Industrial Wastewater Treatment and Discharge.

The overall emissions reported for the Waste sector and related trend analysis included in this note is limited to the period 2005-2013. Given that emission estimation is possible over the time period from 2005-2014 for the two source sub-categories of '4A2 Unmanaged Waste Disposal Sites' and '4D1 Domestic Wastewater Treatment and Discharge' due to availability of relevant datasets for year 2014, the corresponding estimates for year 2014 have been included as well in the relevant methodological sections 3.4 and 3.5 for these two source sub-categories in this document.

The emission estimates are based primarily on aggregated secondary data collected by ICLEI South Asia from published documents and reports of relevant government departments, nodal agencies and research institutions in the Waste sector. Interactions were held with experts and representatives from some of these

¹¹ Available at <https://www.ipcc-nggip.iges.or.jp/public/2006gl/>

¹² Ministry of Environment and Forests, Government of India (2012): India - Second National Communication Report, 2012 to the UNFCCC, Available at: <http://unfccc.int/resource/docs/natc/indnc2.pdf>

¹³ Ministry of Environment, Forest and Climate Change, Government of India (2015): India - First Biennial Update Report to the UNFCCC. Available at <http://unfccc.int/resource/docs/natc/indbur1.pdf>

organizations to seek inputs on data availability and the emission estimation approach where required. The methodological approach adopted and the emission estimation results have been finalized post a peer-review by the WRI India team.

Planning and methodology improvement:

With regard to emission estimation, the phase-II of the GHG Platform India project involved

- Expanding the national time series of emissions estimation prepared in phase- I (covering the years 2007-2012) for all sectors and 3 gases (CO₂, CH₄, N₂O) to the years 2005 to 2013 (or up to year 2014 subject to data availability)
- preparation of a time series of emission estimates for all sectors and sub-sectors for each Indian state for the same period as the expanded national estimates

The inventory planning commenced with the project partners jointly identifying the activities and developing a broad work plan to meet these objectives. Specific work plans and approaches were drawn up by each of the sector leads to undertake the exercise for the respective sectors, including ICLEI South Asia for the Waste sector.

The data gaps and steps to be taken to improve reliability of the phase-I emission estimates were identified, particularly with regard to industrial wastewater related emissions in the Waste sector. Detailed methodologies for preparation of the expanded national-level estimates and the state-level estimates were developed for each of the key source categories and sub-categories.

A series of round tables were organized in different regions of the country under the GHG Platform India to reach out to potential users of the Platform's outputs such as policymakers, research institutions, experts and the media. The round tables also aimed to capture feedback on the methodology, suitability of data sets, analyses undertaken, and conclusions based on phase-I emission estimates and to contribute to ongoing work under phase-II. ICLEI South Asia organized a sector roundtable in Kolkata and participated in the regional roundtables organised by the Platform partners in Bangalore, Mumbai and Delhi. Based on feedback received from the roundtables, it was decided to expand the scope of assessment to cover rural areas as well in the phase-II domestic wastewater emission estimation.

To prepare the expanded national-level emission estimates, secondary data research was undertaken for the years 2005, 2006, 2013 and 2014 for all sub-sectors with regard to parameters such as industrial production, domestic and industrial waste water generation rates, treatment and discharge pathways, municipal solid waste generation rates, waste composition, etc. Interactions have been held with relevant departments and institutions as needed. The domestic wastewater and industrial wastewater emission estimates for 2007-2012 have been revisited and have been refined based on updated information on activity data and related parameters. The inventory development process involved regular discussions and reporting of progress between the project partners. Reporting formats were also developed for clear and transparent documentation and reporting of the methodology and results of the emission estimation.

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:

- The input activity data for each emission source sub-category has been selected from that available in different datasets by duly factoring in its relative time-series consistency and temporal and spatial applicability.
- The input data in the calculation sheets has been checked internally for transcription errors on a sample basis for all the 3 sub-sectors.
- The calculation spreadsheets have been checked for correct application of formulae, activity and factors and to ensure that calculations are correct. Manual calculations have been carried out for a part of the emission estimates in all 3 sub-sectors to verify the spreadsheets results.
- Appropriate recording, conversions, processing and consistency of measurement units for parameters and emission has been checked across the reporting period.
- The emission estimates of each year of the reporting period have been compared to check for consistency in trends and detect any major deviations which cannot be correlated with corresponding changes in activity data and/or emission factors.
- A sheet providing an overview of sector, level of aggregation, reporting period, authors, reporting entity, version and usage policy has been included in the source category emission calculation spreadsheets that

are linked to the main emission reporting spreadsheet. The emission calculation equations, relevant data and parameter values used, intermediate formulae and cells wherein these are linked, and emission results are clearly depicted in the calculation spreadsheets for all 3 sub-categories.

- The reporting document has been checked to confirm all relevant references and secondary sources for activity data and emission factors have been included and documented.
- Emission source categories and sub-categories included and excluded in the emission estimates have been transparently reported in sections 1.7 and 3.3 of this note. Any known gaps in the emission estimates along with rationale of assumptions used to address data gaps have been clearly indicated for each of the sub-sectors in sections 3.4, 3.5 and 3.6.

Once the draft emission estimates have been prepared, these have been peer reviewed by the WRI team and feedback from the peer review process has been incorporated before finalization.

Data collection, processing, and storage

To ensure that the estimates from the emission source categories represent the existing condition of waste management in India, it has been sought to use country-specific data in the assessment to the extent possible. The data has been primarily collected through an extensive secondary research. The data collection exercise focussed on gathering reliable information from published documents and reports of relevant government departments, nodal agencies and research institutions including Central Pollution Control Board (CPCB), the National Environmental Engineering Research Institute (NEERI), industry associations, and the Ministry of Urban Development among others. Discussions on methodology, activity data available and emission factors being used, were held with relevant organizations such as the CPCB, NEERI, industry associations, and SPCB in-person and over telephone. The data collected was in various forms and units and has been assessed to ensure its applicability within the emission estimation boundaries and subsequently processed for further use.

The emission estimation method, reporting period, boundaries, year-wise activity data, emission factors and relevant parameters along with data sources and any assumptions to address gaps, and national-level emission results have been transparently recorded in this reporting document and in excel spreadsheets to provide clear understanding and to enable reconstruction of the emission estimations as required. All information collected and compiled for the emission estimates has been archived electronically in separate folders for future use as needed along with copies of relevant references or data sources. The final emission estimates and reporting documents are published and available on the GHG Platform India website (www.ghgplatform-india.org).

1.4 General description of methodology and data sources

Estimation methods:

The emission estimates for the Waste sector are based on the 2006 IPCC Guidelines for National GHG Inventories. The emission factors and activity data used in the emission estimates are a mix of country-specific data and default values specified by the 2006 IPCC Guidelines. While use of country-specific activity data has been prioritized, IPCC default values are used where requisite reliable country-specific activity data is not available. Country specific values of emission factors are used for the degradable organic carbon (DOC) content to estimate CH₄ emissions from solid waste disposal.

The tier method selected for each of the 3 emissions source sub-categories included in this assessment is guided by the decision trees provided in the 2006 IPCC Guidelines and is based on data availability. The estimation approach uses a combination of Tier 1 and Tier 2 methods, with limitations in availability of disaggregated country-specific data and emission factors restricting use of Tier 2 and Tier 3 methods. Further details on the Tiers used for the 3 emissions source sub-categories in the Waste sector are provided in the sections 3.4.2, 3.5.2 and 3.6.2 of this note for each of the sub-sectors.

Activity data collected and relevant emission factors selected have been used to calculate emission estimates using the following basic principle given in the 2006 IPCC Guidelines:

$$GHG\ emission = activity\ data \times emission\ factor$$

Complex calculations and models based on this basic principle are outlined for the Waste sector in the 2006 IPCC Guidelines and used in the emission estimates for the 3 sub-categories included in this assessment.

The emissions estimates have been reported in Table I and Table I8 in this note in terms of CO₂ equivalent (CO₂e) for CH₄ and N₂O gases using the respective Global Warming Potential (GWP) values over a 100-year time horizon, as provided by the IPCC in its Second Assessment Report, 1996^{Error! Bookmark not defined.} and the latest updated GWP values in the Fifth Assessment Report, 2014^{Error! Bookmark not defined.}. India's Second National Communication Report¹² and the First Biennial Update Report¹³ both use 100 year GWP values from the IPCC Second Assessment Report, 1996¹⁴. To ensure consistency with the official GHG inventory submissions, the estimates reported in terms of CO₂e throughout this note, with the exception of Table I and Table I8, use the GWP values from the IPCC Second Assessment Report, 1996.

A brief description of the considered source categories, the activities and emission sources therein, and the method of estimation is provided below.

1. Solid waste disposal

Solid waste disposal includes CH₄ emissions from solid waste collected and disposed at specific waste disposal sites. This assessment considers disposal of municipal solid waste, which typically includes waste from households, gardens and parks, and commercial and institutional areas in urban areas. Given that solid waste in rural areas does not decompose under anaerobic conditions due to lack of waste management and disposal facilities, emissions from rural solid waste are considered to not be significant, in line with India's Second National Communication¹² and Biennial Update Report, 2015¹³.

The First Order of Decay (FOD) method has been used to estimate the CH₄ emission from MSW disposal over the years. The method assumes that the degradable organic component in waste decays slowly over a few decades, during which CH₄ is released. Based on the IPCC guidance¹⁵ on the FOD model and India's Second National Communication¹², a period of 50 years is considered appropriate for CH₄ emissions from a given quantum of waste to come down to significant level. Therefore, the historical waste disposal and resultant emissions have been estimated for a period of 50 years prior to 2005 i.e. 1954-2004 along with emissions for the reporting period from 2005 to 2014.

A combination of Tier 1 and Tier 2 approaches is used in the emission estimation. Prevalent waste management practices such as open dumping/unmanaged landfill, waste characteristics and composition, and per capita waste generation rates over the years in Indian cities have been factored in the methodology and emission estimation.

2. Domestic wastewater treatment and discharge

Domestic wastewater emissions have been estimated for 2005-2014 for CH₄ and N₂O gases. The characteristics of the domestic waste water and consequently the associated GHG emissions vary from place to place depending on factors such as economic status, community food intake, water supply status, treatment systems and climatic conditions of the area. To account for these variations, the population generating domestic wastewater has been categorized based on income group and location –for the urban and rural areas. Domestic wastewater treatment systems and pathways considered include centralized treatment plants, septic tanks, pit latrines, open/closed sewers, and anaerobic digesters. N₂O emissions occurring as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea have also been considered.

A Tier 1 approach has been used to estimate CH₄ and N₂O emissions for this source category.

3. Industrial wastewater treatment and discharge

The 12 industrial sectors considered in the assessment include Iron and Steel, Fertilizers, Meat, Sugar, Coffee, Pulp and Paper, Petroleum, Beer, Soft Drinks, Rubber, Dairy, and Tannery -sectors which have relatively high

¹⁴ Available at https://www.ipcc.ch/ipccreports/sar/wg_i/ipcc_sar_wg_i_full_report.pdf

¹⁵ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

organic wastewater generation and thereby lead to significant CH₄ emissions on its treatment and discharge. The emission estimation has been conducted for years 2005-2013 due to unavailability of activity data on industrial production for the year 2014. A Tier I approach has been used to estimate CH₄ emissions due to industrial wastewater treatment and discharge.

To ensure consistency across the sectors, overall emissions reported for the Waste sector in this document are limited to the years 2005-2013. However, given that the relevant data for year 2014 is available for the source sub-categories of '4A2 Unmanaged Waste Disposal Sites' and '4D1 Domestic Wastewater Treatment and Discharge', the corresponding estimates for year 2014 have been included in the relevant methodology sections of this note for these source sub-categories.

Data Sources:

As indicated previously, it has been sought to use country-specific data in the emission estimates. Activity data has been primarily sourced from official data reported in publicly available web-based publications and statistical documents of relevant government departments, nodal agencies, industrial departments and research institutions including NEERI, CPCB, Census of India, Annual Survey of Industries, industry associations, Ministry of Urban Development and others as indicated in the Table 5.

The CPCB is a statutory government organization responsible for collecting information on generation and treatment of solid waste and wastewater from all states and send requisite directives for necessary measures and therefore is a key source of activity data relating to solid waste disposal and domestic wastewater. Information on total volume of wastewater generated from industrial sectors is not available with the CPCB as well as relevant government departments and thus a Tier I approach which uses industrial production to estimate volume of wastewater generation is used in the case of industrial wastewater. Therefore, data sources for industrial production data for the 12 sectors under consideration include corresponding nodal industry departments and bodies, industry associations, and research/studies conducted in these sectors.

NEERI is a government research institute working on solid waste and wastewater¹⁶ in the country and has also been involved in GHG emission estimation for the Waste sector in India's National Communication. Given the experience of NEERI in waste management, peer reviewed literature from NEERI have been used as a data source for activity data, emission factors and related parameters related to solid waste disposal as well as domestic and industrial wastewater. Data on historical per capita solid waste generation rates have been taken from a report published by The Energy Resources Institute (TERI)⁴⁴. Data on the population and availability of diverse types of wastewater disposal facilities in households from the Census of India has been used in the solid waste and domestic wastewater emission estimates.

As mentioned earlier, discussions were conducted with experts from CPCB and NEERI over the methodology and datasets available for solid waste and wastewater. Inputs were also received on prevalent wastewater treatment technologies for industry sectors such as Iron & Steel, Rubber, Petroleum, Beer, Dairy, Soft drinks, Coffee, Meat that are considered in this assessment. Discussions were also held with representatives from industrial departments and associations including the Ministry of Statistics and Programme Implementation, Central Board of Excise and Customs - Central Excise, the Coffee Board of India, All India Brewers Association, the Rubber Board on industrial production datasets. Inputs received helped to ascertain the status of available industrial production data and gaps therein and identify potential data sources for Beer, Soft drinks, Coffee and Rubber sectors in particular.

The emission factors are sourced primarily from India's national communication documents to the UNFCCC, research documents and publications of NEERI, and the 2006 IPCC Guidelines on national GHG inventories, in this order of preference. While the importance of using of country-specific emission factors was well understood, the limited availability of data and specific emission factors for India has necessitated the use of the IPCC default values to a considerable extent in the emission estimates. Further details of specific data sourced from each of the entities mentioned above are given in the corresponding detailed sections on methodology for the 3 emissions source sub-categories.

¹⁶ NEERI's focus areas on solid waste include technical and scientific research on solid waste quantification, solid waste characterization, development of better and scientific solid waste management practices and treatment technologies, climate change related issues such as methane emissions from solid waste disposal etc. Regarding wastewater, NEERI works on research towards wastewater generation and management, physio-chemical characteristics, recycling and recovery for both domestic and industrial wastewater along with technology development and design of wastewater treatment systems. Available at www.neeri.res.in

Table 5: Principal Sources of Data for Source Categories and Sub-Categories

IPCC ID	NAME OF SECTOR	PRINCIPAL ACTIVITY DATA SOURCE	PRINCIPAL COLLECTION MECHANISM
4A2	Unmanaged Waste Disposal Sites	CPCB; NEERI; Central Public Health and Environmental Engineering Organisation (CPHEEO), Ministry of Urban Development; TERI; 2006 IPCC Guidelines on national emission inventories	Published data from reports, manuals and studies from the web
4D1	Domestic Wastewater Treatment and Discharge	CPCB; NEERI; Census of India; NSSO, Ministry of Statistics & Programme Implementation (MOSPI); 2006 IPCC Guidelines on national emission inventories	Published data from reports, studies and statistical publications from the web
4D2	Industrial Wastewater Treatment and Discharge	• NEERI • Ministry of Steel • Indian Bureau of Mines • The Fertilizer Association of India • Annual Survey of Industries, Ministry of Statistics and Programme Implementation • National Federation of Cooperative Sugar Factories Limited • Coffee Board, Ministry of Commerce and Industry • Petroleum Planning and Analysis Cell, Ministry of Petroleum & Natural Gas • Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture • Office of the Principal Scientific Adviser to the Government of India • Network for Certification and Conservation of Forests • Rubber Board, Ministry of Commerce and Industry • Food and Agriculture Organization (FAO) • Centre for Science and Environment (CSE) • 2006 IPCC Guidelines on national emission inventories	Published data from reports, studies and statistical publications from the web;

Note: Related web-links for the data sources are given in the corresponding detailed methodology sections 3.4.2, 3.5.2 and 3.6.2 for the emission source categories.

1.5 Brief description of key source categories

It is observed that the 3 source categories - Unmanaged waste disposal sites (4A2), Domestic wastewater treatment and discharge (4D1), and Industrial wastewater treatment and discharge (4D2) – considered in the emission estimates each contribute to more than 5% of the Waste sector emissions across the reporting period from 2005-2013. Domestic wastewater treatment and discharge (4D1) contributes to 60% of the overall emissions between the years 2005-2013. This is followed by Industrial wastewater treatment and discharge (4D2) which accounts for 24% and Unmanaged waste disposal sites (4A2) which has a share of 16% in the total emissions from 2005-2013.

Therefore, in line with the 2006 IPCC Guidelines for National GHG Inventories all the 3 source categories are identified as key source categories within the Waste sector.

1.6 Uncertainty Evaluation

Since the emission estimation for the Waste sector uses complex calculations and models involving compilation and processing of a number of input parameters (i.e. activity data and emission factors), the availability and quality of the input data or lack thereof is bound to bring in uncertainty in the estimation. Comprehensive quantitative and qualitative reporting of uncertainties requires a detailed understanding of the processes of compilation and reporting of input parameters used in the estimates. The lack of reliable and updated country-specific data is a key challenge encountered for all the 3 Waste sub-sectors considered in the emission estimation. Due to the lack of disaggregated data, an aggregation based top-down approach has been

used in the emission estimation, which contributes to propagation of inherent errors in the input data into the estimates. Given the absence of quantitative and qualitative information to help identify inaccuracies in the input datasets, it is difficult to make an overall statement of uncertainty for the Waste sector estimates.

A qualitative assessment of the potential sources of inaccuracy for each of the source categories considered in the Waste sector estimates has been undertaken at present, to the extent possible, with reference to the IPCC guidance and default uncertainty values. Assumptions made in the emission estimation have been clearly reported and a sensitivity analysis has been conducted for key parameters and assumptions for all the 3 sub-sectors. The emission estimate uncertainties are assessed to be relatively higher for the CH₄ emission estimates from 'Industrial wastewater treatment and discharge' as compared to 'domestic wastewater treatment and discharge' and 'solid waste disposal'. Recommendations relating to data gathering and disaggregation suggested at the end of this report will help in refining the inventory and reducing uncertainties.

Going forward, it is sought to undertake a more comprehensive uncertainty analysis, with partner organizations under the GHG Platform India attempting to better identify data gaps and quantify related uncertainties across sectors while proposing adequate measures to fill such data gaps.

1.7 General Assessment of Completeness

Emissions from the source categories '4B Biological treatment of solid waste' and '4C Incineration and open burning of waste' are not included in the estimates due to the lack of reliable data for these sources and the absence of considerable number of waste incineration and composting facilities for a large part of the reporting period, especially pre-2010.

Emissions from solid waste disposal are limited to disposal of municipal solid waste in this assessment. Possible emissions from industrial waste and other waste such as clinical waste and hazardous waste are not considered under this source category due to the lack of published information from reliable sources on the generation and management of these solid waste streams in India. Given the lack of solid waste management systems in rural areas, a majority of the solid waste in rural areas does not decompose under controlled/semi-controlled anaerobic conditions and thereby does not contribute to significant GHG emissions. Thus, the assessment considers GHG emissions from solid waste disposal in urban areas. Further, most of the solid waste disposal sites in India are not scientifically constructed and are inadequately managed as per national government guidance. The sites are also observed to be shallow¹⁷ in general. Therefore, the emission estimates account for the source category '4A2: Unmanaged waste disposal sites' which is deemed applicable for India.

Given that during the reporting period, an insignificant quantum of waste is disposed in scientifically designed and managed waste disposal sites, the source category of '4A1: Managed waste disposal sites' is not yet applicable in the Indian context and therefore, not considered in the present estimation. It is widely acknowledged and is corroborated from reports that the prevalent mode of waste disposal is in unmanaged open disposal sites and hence '4A3: Uncategorized waste disposal sites' is also not considered.

Regarding the industrial wastewater estimates, 12 industry sectors having significant organic load in their effluent and thereby generating significant GHG emission are included. These sectors are identified using India's National Communication reports, the 2006 IPCC guidelines for National GHG inventories¹⁸, literature from NEERI and largely include the significant industrial wastewater related GHG emission sources in the country. Estimates for domestic wastewater cover both the urban as well as rural population and are considered to sufficiently capture the relevant emission sources.

2 Trends in Emissions

India's Waste sector is estimated to contribute to GHG emission of 89.14 Million tonnes (Mil. tonnes) of CO₂e in the year 2013 (see Figure 3). GHG emissions from treatment and discharge of domestic wastewater have accounted for the highest share of the Waste sector emissions over the reporting period, contributing to

¹⁷ Unmanaged solid waste disposal sites having depths of less than 5 meters are classified as shallow as per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

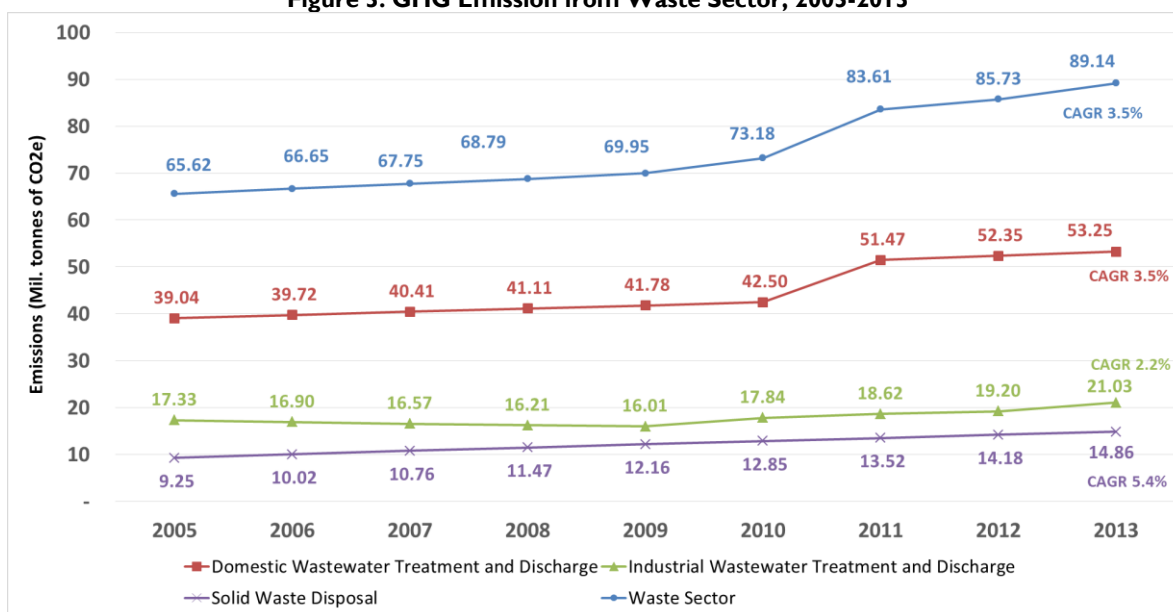
¹⁸ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

nearly 60% of the total emissions in the Waste sector in 2013 (see Figure 4). Industrial wastewater treatment and discharge was the 2nd largest contributor to the total GHG emissions in the Waste sector, with a share of 23.5% in 2013, followed by solid waste disposal which contributed to 16.7% of the country's Waste GHG emissions.

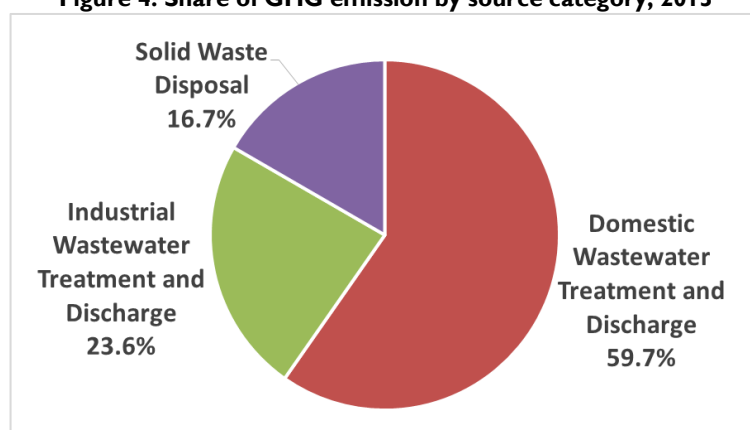
Waste sector GHG emissions have increased by 36% in the year 2013 as compared to year 2005, rising at a CAGR of 3.9% over the reporting period from 2005-2013. Emissions from solid waste disposal have registered the highest CAGR of 6.1% per year among the 3 sub-sectors. GHG emissions from the domestic and industrial wastewater have grown at CAGR of 4.0% and 2.5% respectively on average from 2005 to 2013. The trend of the overall emission is observed to be quite steady with a relatively higher rise between for the year 2010 and 2011 (see Figure 3). This can be correlated with the corresponding increase in the estimated domestic wastewater emissions¹⁹.

Figure 3: GHG Emission from Waste Sector, 2005-2013



(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

Figure 4: Share of GHG emission by source category, 2013

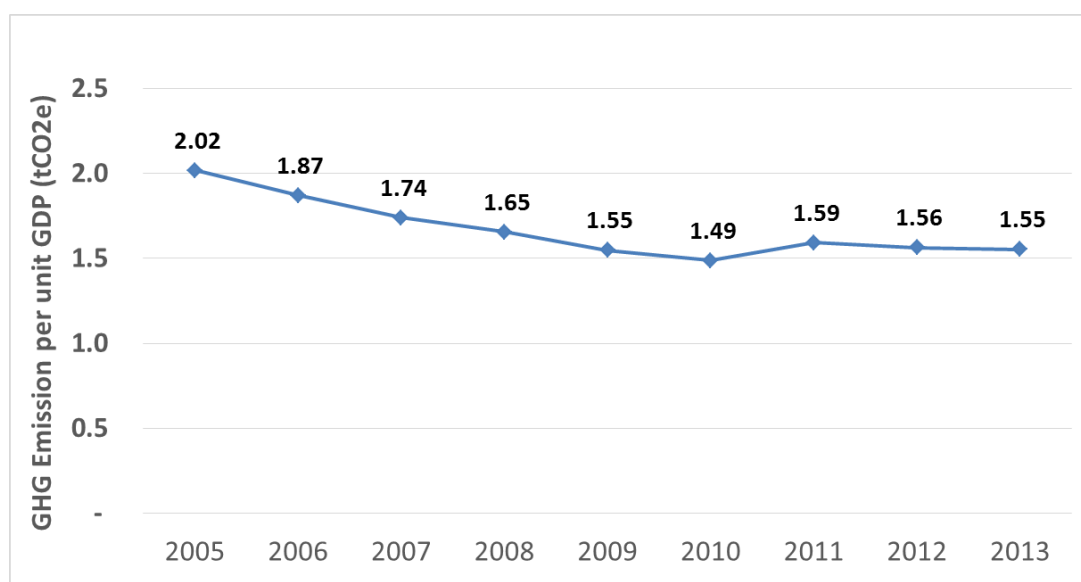


¹⁹ The overall increase in GHG emissions from domestic wastewater over the reporting period from 2005-2013 is driven by the growing population and changing patterns of use of different treatment systems such as septic tanks, which have a higher methane generation potential. Constraints in availability of data and assumptions used to address the same contribute to the step change observed in emissions from 2010 to 2011. In the domestic wastewater emission calculations, Census 2001 data on the use of different wastewater discharge/treatment systems by rural households has been used in the estimation from year 2005-2010 since data is not available for these years. For the years 2011-2013, Census 2011 data on use of different wastewater discharge/treatment systems has been used from the year 2011 onwards. Since the proportion of population using different wastewater treatment systems (such as septic tanks, latrines, sewer systems, direct discharge without treatment) changes in year 2011 as compared to the preceding years, the relatively higher change is observed for this year.

(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

The emission intensity of the Waste sector emissions, in terms of GHG emission per unit GDP, is observed to have decreased by 23% in 2013 as compared to the base year of 2005, falling at a CAGR of -3.2% over the reporting period between 2005 to 2013 (see Figure 5). Per capita emissions from the Waste sector increased from 0.06 tonnes of CO₂e in year to 0.071 tonnes of CO₂e in the year 2013, growing at a CAGR of 2.1% per annum from 2005 to 2013.

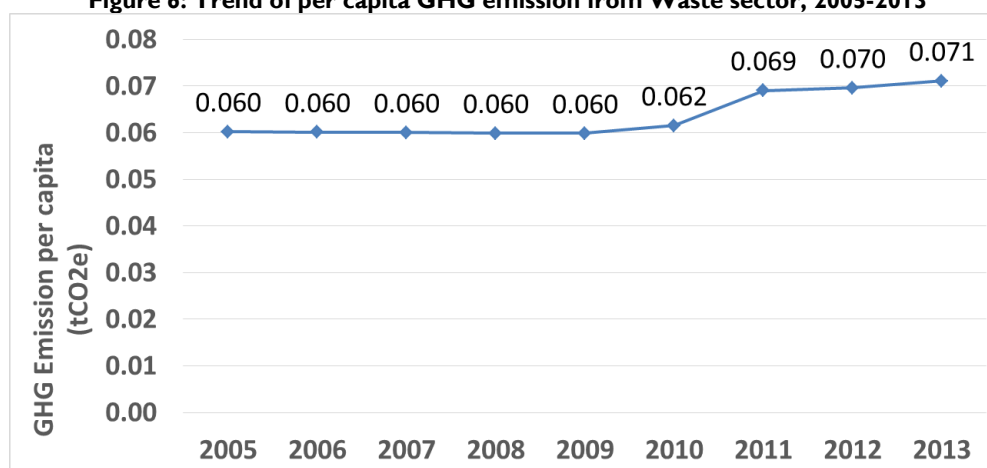
Figure 5: Trend of Waste sector GHG emission per unit GDP* (tonnes of CO₂e per Million INR at constant 2004-05 prices), 2005-2013



(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series; GDP based on Central Statistical Organization, 2014 data)

*Note: Since GDP is reported on financial year basis, the GDP data for 2005-06 has been used to estimate the emission intensity for 2005, GDP data for 2006-07 has been used to estimate the emission intensity for 2006 and so on.

Figure 6: Trend of per capita GHG emission from Waste sector, 2005-2013



(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

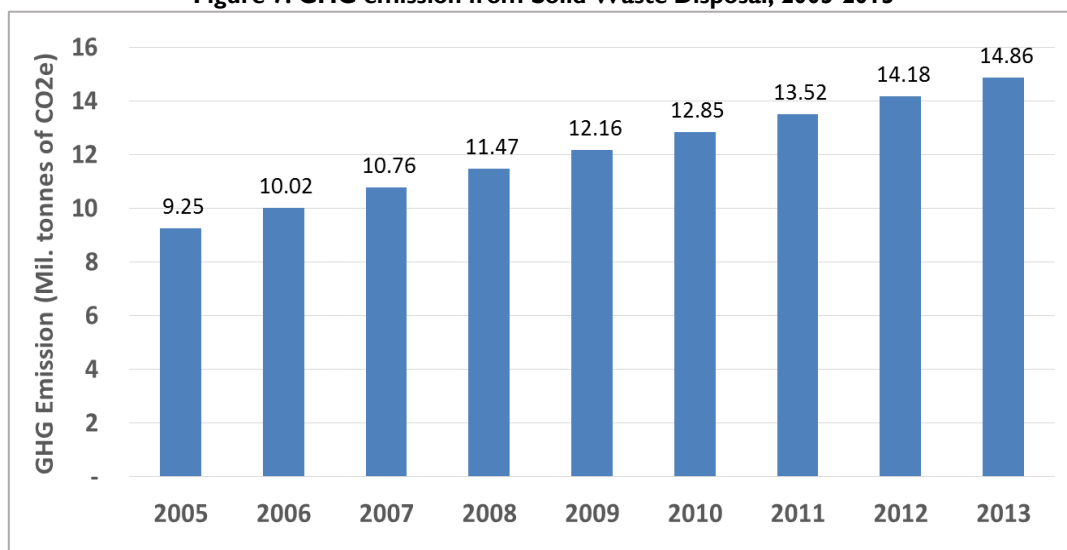
The trends observed and related analysis for each source category considered in the emission estimates is presented below.

4A Solid Waste Disposal

CH₄ emission due to solid waste disposal is estimated to have increased by 61% on an absolute basis from the year 2005 to 2013. Solid waste disposal contributed to GHG emission of 14.86 Mil. tonnes of CO₂e in 2013 as

against 9.25 Mil. tonnes of CO₂e in 2005 (see Figure 7). This source category is observed to have the highest year-on-year growth on average in the Waste sector, with a CAGR of 6.1% from 2005 to 2013.

Figure 7: GHG emission from Solid Waste Disposal, 2005-2013



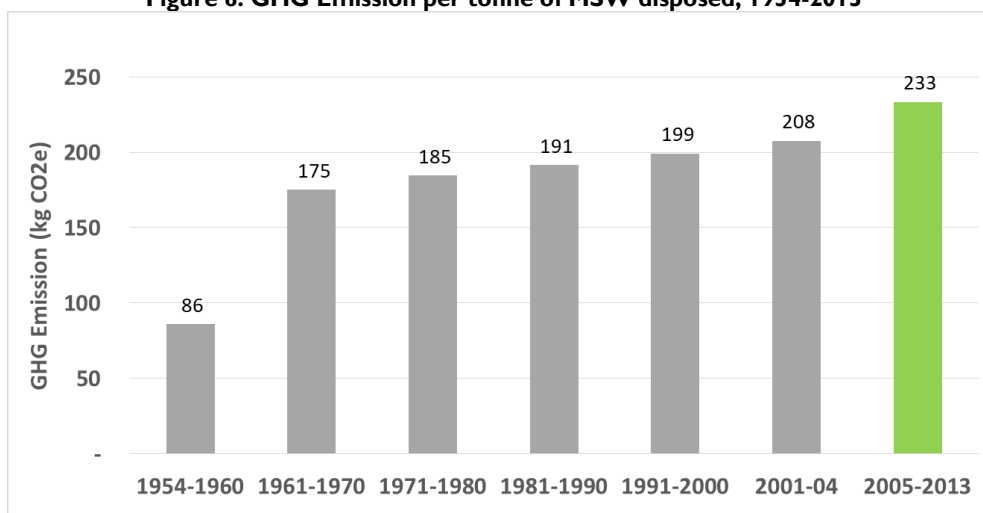
(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

Changing trends in GHG emission are primarily due to change in the total quantum of solid waste, its composition, and the method of disposal and characteristics related to the disposal site. In the short-term for the reporting period from 2005-2013, the rise in solid waste disposal emissions is driven by increasing waste generation rates in cities across the states and growing population, leading to higher quantum of waste going to disposal sites. The per capita solid waste generation has been growing by 1.3% per year²⁰ over the past two decades.

Over the long-term, the changing composition of municipal solid waste is seen to contribute to rising emissions, with higher emissions generated from every tonne of waste that is being disposed. GHG emissions per tonne for solid waste disposal have more than doubled from 86 kg of CO₂e per tonne of solid waste disposed during 1954-60²¹ to 233 kg of CO₂e per tonne of solid waste disposed during 2005-2013 (refer Figure 8).

²⁰ Indicates simple annual growth rate. CAGR growth rates, where used, have been denoted as such in the document and all other growth rates mentioned throughout this document refer to simple growth rates.

²¹ This analysis and insight into long-term emission related trends for solid waste is a result of the first order decay (FOD) method being followed in this exercise for estimation of emissions from solid waste disposal. The FOD method considers that waste deposited in a disposal site at a point in time decomposes gradually and continues to undergo anaerobic digestion again and generate CH₄ over a long period of time (around 50 years). CH₄ emission will be generated until the waste deposited in the disposal site decomposes completely and reaches its full methane generation potential. Therefore, to fully account for emissions from solid waste disposal in our exercise for year 2005, it is necessary to estimate emissions for a 50-year period before this year i.e. from 1954-2004. In Figure 8, GHG emission per tonne for solid waste disposed for the emission estimation period of this exercise is depicted by the green coloured bar while the historic long trend of GHG emission per tonne of waste disposed that derives from the FOD method for the previous 50-year period is depicted by grey coloured bars.

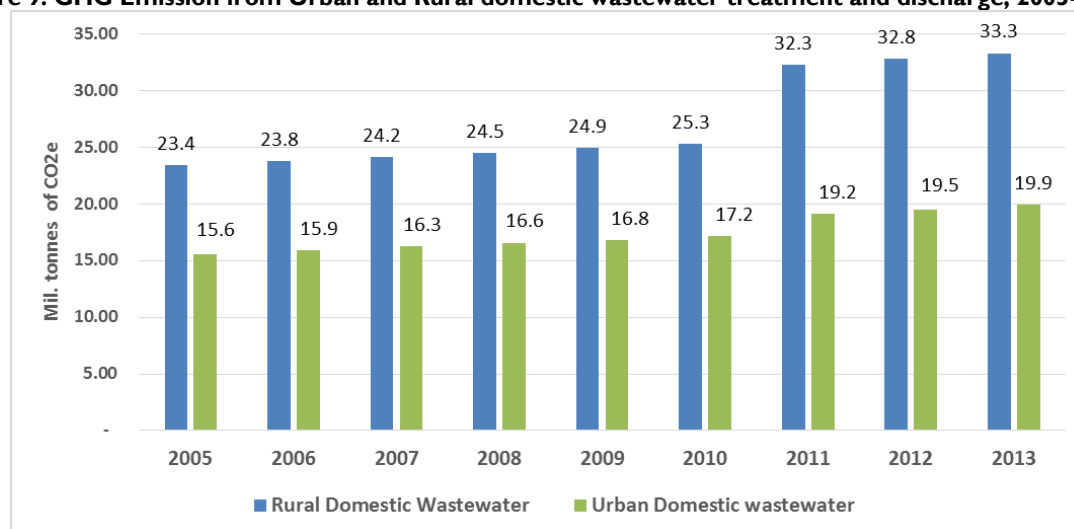
Figure 8: GHG Emission per tonne of MSW disposed, 1954-2013

(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

Note: GHG emission per tonne for solid waste disposed for the emission estimation period of this exercise is depicted by the green coloured bar in Figure 8 while the historic long trend of GHG emission per tonne of waste disposed that derives from the FOD method for the previous 50-year period is depicted by grey coloured bars.

4DI Domestic Wastewater Treatment and Discharge

The total domestic wastewater related emissions from urban and rural areas are presented in Figure 9. Emissions from rural domestic wastewater are seen to contribute to about 60% of the total emissions from domestic wastewater in the country across the period from 2005-2013. The rural population, however, accounted for 72.19% and 68.85% of India's population in the year 2001 and 2011 respectively. Therefore, given that a smaller number of the country's population is residing in urban areas, the corresponding GHG emission generated from urban domestic wastewater is considerably higher. Per capita GHG emissions from domestic wastewater for the urban population were 36.4 kg as compared to 24.2 kg for the rural population in the year 2013, a difference of 50%.

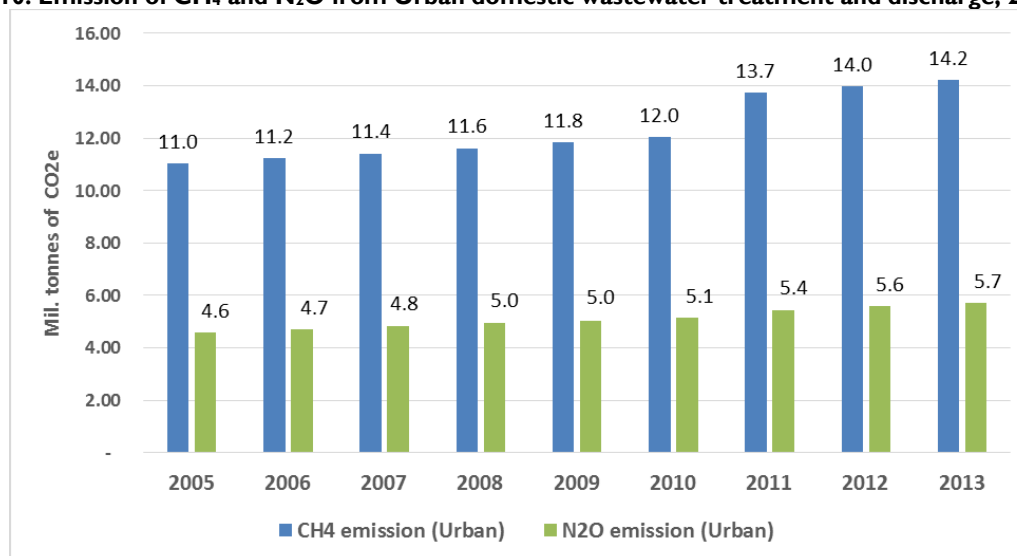
Figure 9: GHG Emission from Urban and Rural domestic wastewater treatment and discharge, 2005-2013

(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

Within urban areas, CH₄ emissions are estimated to be much higher than N₂O emissions, accounting for 71% of the total GHG emission from urban domestic wastewater (see Figure 10). CAGR of CH₄ and N₂O emissions from urban domestic wastewater over the reporting period of 2005-2013 is observed to be 3.22% and 2.8% respectively. The N₂O emission has a direct correlation with the human protein consumption and the size of urban and rural population consuming this protein. Protein is a source of nitrogen and N₂O emissions occur on degradation of this nitrogen in the wastewater. N₂O emissions show a steady trend in line with the steadily rising nutritional intake of protein and increase in urban population over the years.

CH₄ is emitted from wastewater when it is treated or disposed anaerobically. Therefore, CH₄ emissions have a direct correlation with the percentage of waste water that is treated or discharged through different systems or pathways. CH₄ emission is also influenced by the income-levels since accessibility and usage of different wastewater treatment systems/pathways varies by income-groups. However, the constraints in data availability limit the inferences that can be drawn from trends with regard to the implications of better access to wastewater collection and treatment systems. Since year-on-year information on distribution of wastewater treatment systems is not available and constant values have been used for degree of utilization for the urban population across the reporting period, the trend of CH₄ emissions, more or less, reflects the urban population growth trend. According to latest Census data in 2011, the proportion of urban population is 31.15% in 2011, a rise of 12%, in comparison to 2001 (27.81%). This higher proportion of urban population in 2011 also, implies an increase of 11.6% in the estimation of CH₄ emissions for 2011 as compared to 2010. The annual growth rate of CH₄ emission from urban domestic wastewater drops down to about 2% from 2011-2013, in line with the steady population growth considered in the calculations

Figure 10: Emission of CH₄ and N₂O from Urban domestic wastewater treatment and discharge, 2005-2013



(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

Note: CH₄ and N₂O emission have been converted to CO₂ equivalent values and depicted in this chart.

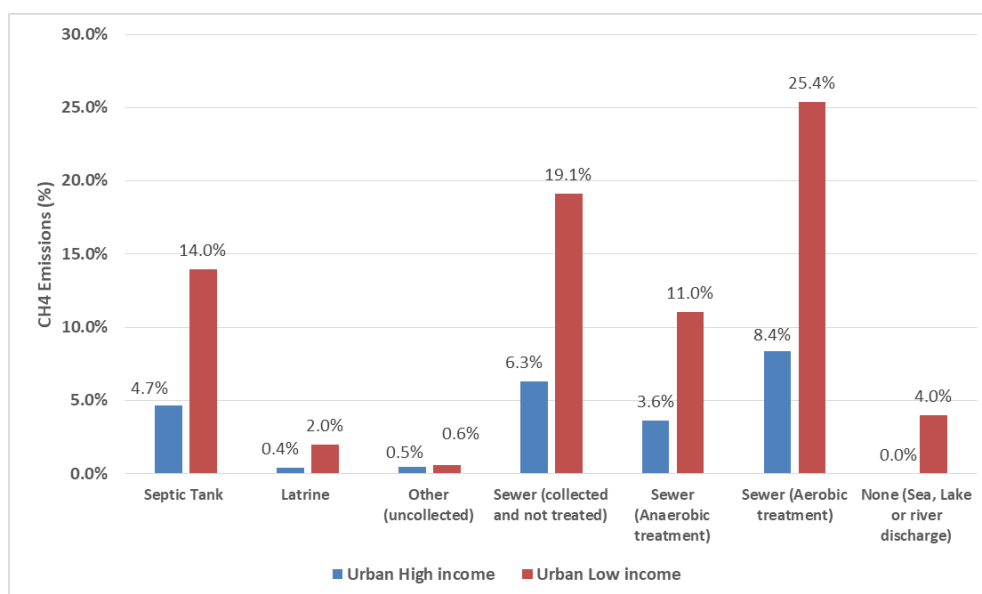
It is seen that aerobic treatment systems contribute to a third of the CH₄ emissions from urban domestic wastewater (see Figure 11). This is mainly due to the existing aerobic treatment-based sewage treatment plants (STPs) in the country not being well managed. The ‘methane correction factor’ value for ‘not well managed aerobic systems’ is 0.3 as against a ‘methane correction factor’ value of 0 (and therefore no CH₄ emission) for ‘well managed aerobic treatment systems’²². Therefore, it is important to manage these aerobic treatment systems effectively.

Due to insufficient installed capacity and operational inefficiencies of STPs, some portion of wastewater that is collected through the sewer network is not treated downstream. The wastewater that is collected through sewer systems but not flowing to a STP (i.e. Sewer (collected & not treated) category) usually stagnates and leads to considerable CH₄ emission, contributing to 25% of the CH₄ emissions from urban wastewater in total. It is therefore important to ensure that domestic wastewater collected through sewer network is treated in efficiently operating sewage treatment plants. Uncollected systems and septic tanks systems serve 18% of urban high-income population and 14% of urban low-income population respectively and contribute to 19% of the total urban domestic wastewater related CH₄ emissions.

Figure 11: Share of CH₄ Emission by type of Treatment/Discharge system for Urban High-income and Urban Low-income population, 2013

²² 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.

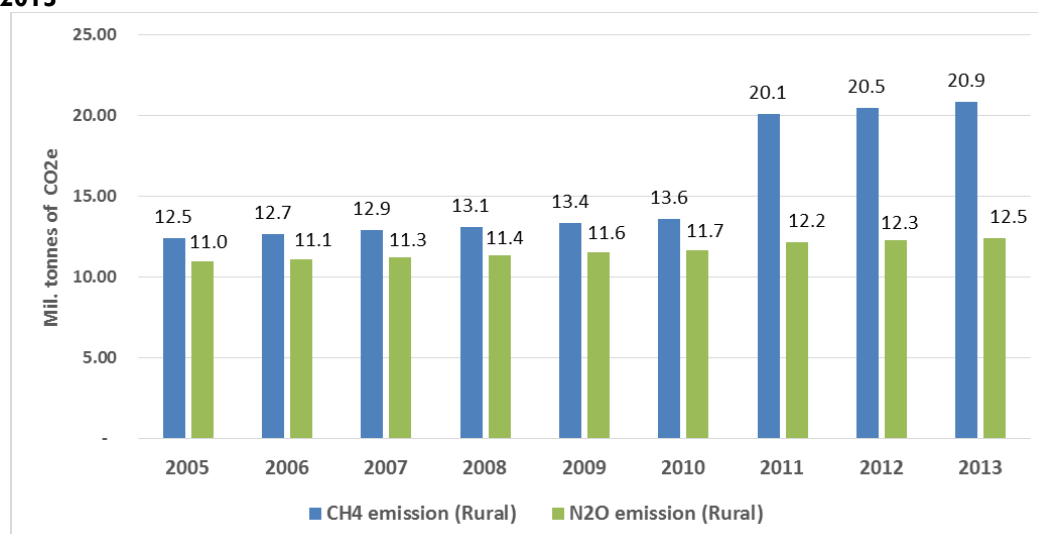
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf



(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

In rural areas, the estimated CH₄ emissions lead the N₂O emissions, with the CH₄ emission rising from year 2011 onwards in particular (see Figure 12). The higher emissions¹⁹ are caused by increased volume of waste water handled in rural areas as reported in Census 2011, especially with the total percent of rural households connected to septic tanks increasing from 5.93% in 2001 to 14.70% in 2011²³.

Figure 12: Emission of CH₄ and N₂O from Rural domestic wastewater treatment and discharge, 2005-2013



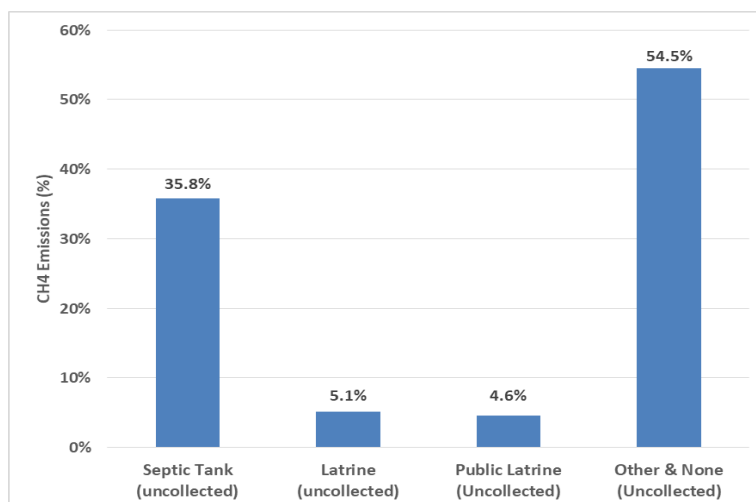
(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

Note: CH₄ and N₂O emission have been converted to CO₂ equivalent values and depicted in this chart.

Domestic wastewater collected through the sewer network in rural areas is not handled or treated downstream and decomposes under aerobic conditions, thereby not leading to CH₄ emissions. Thus, the 'uncollected' wastewater category is the primary source of CH₄ emissions in rural areas (see Figure 13). The highest contributor to CH₄ emissions from rural domestic wastewater is the 'Others/None' category, which refers to the waste water that is not treated and/or discharged into 'ground' and 'rivers, lakes, estuaries, sea'. This is largely driven by the fact that over 70% of rural households are utilizing this mode of wastewater discharge in the absence of wastewater collection systems. Septic tank systems are used by 14.7% of the rural population as per Census 2011²³ and contribute to 36% of the CH₄ emissions from domestic wastewater in 2013.

²³ Available at http://censusindia.gov.in/2011census/hlo/Data_sheet/India/Latrine.pdf

Figure 13: Share of CH₄ Emission by type of Treatment/Discharge system for Rural population, 2013



(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

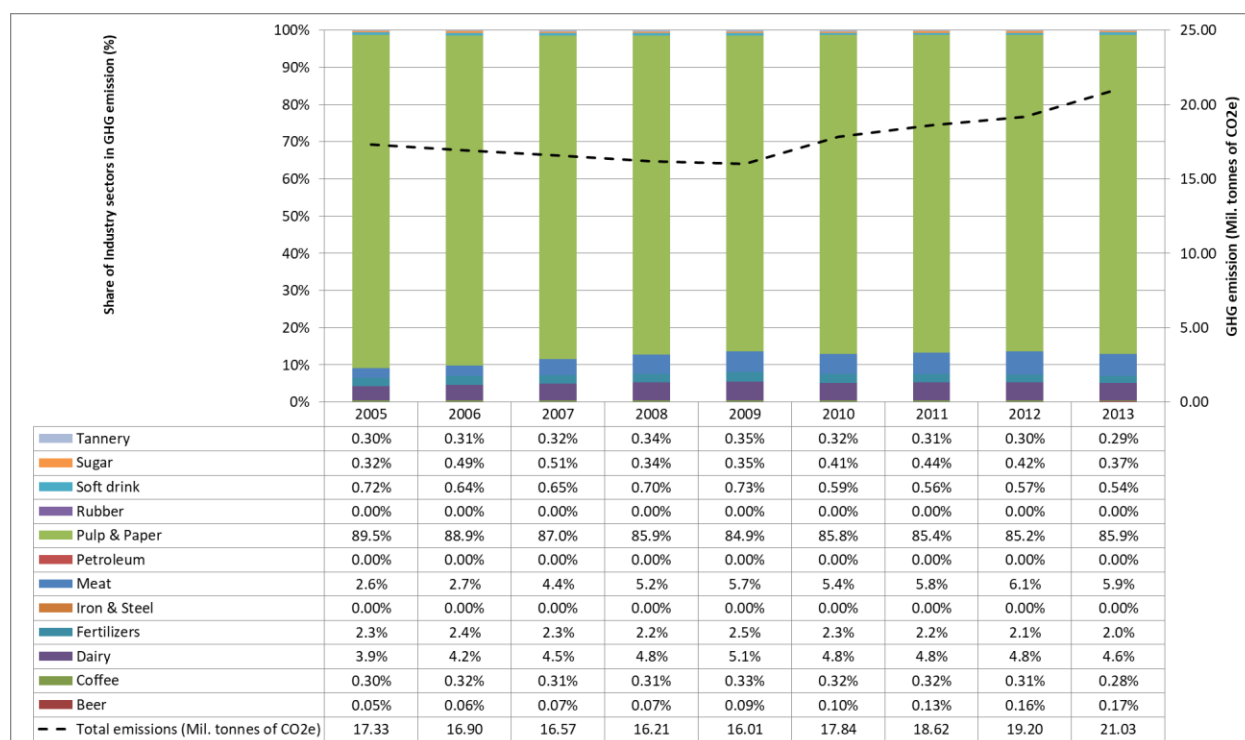
4D2 Industrial Wastewater Treatment and Discharge

National GHG emission estimates for industrial wastewater include 12 industrial sectors - Fertilizers, Meat, Sugar, Coffee, Pulp and Paper, Petroleum, Beer, Soft Drinks, Rubber, Dairy and Tannery, Iron and Steel – production in all 12 sectors results in generation of waste water with significant organic load with potential to release CH₄ emissions, which is dependent on the type of wastewater treatment. As seen from Figure 14, GHG emissions from industrial waste water treatment show a gradual decrease over the period 2005-2009 and an increase from year 2010-2013. This variation in waste water generation is a direct function of the availability of inconsistent information on production and volume of waste water generated for each industry type over the years, which limits drawing inferences from the trends in the emission estimates.

In the absence of recorded information on sector-wise volume of wastewater generated by industries across the country, industrial production is a key parameter required to estimate the total wastewater generation²⁴ by industry sector and the CH₄ emission resulting from its degradable organic concentration and the treatment technology used. However, during the assessment it was observed that the requisite industrial production data for the 12 industrial sectors under consideration is not available in a single source dataset, thereby necessitating the use of multiple data sources for each of the industrial sectors. The inherent inconsistencies in these datasets have impacted the reliability of activity data and the emission estimates. Notable variation is observed year on year in the industrial wastewater emission estimates (see Figure 15).

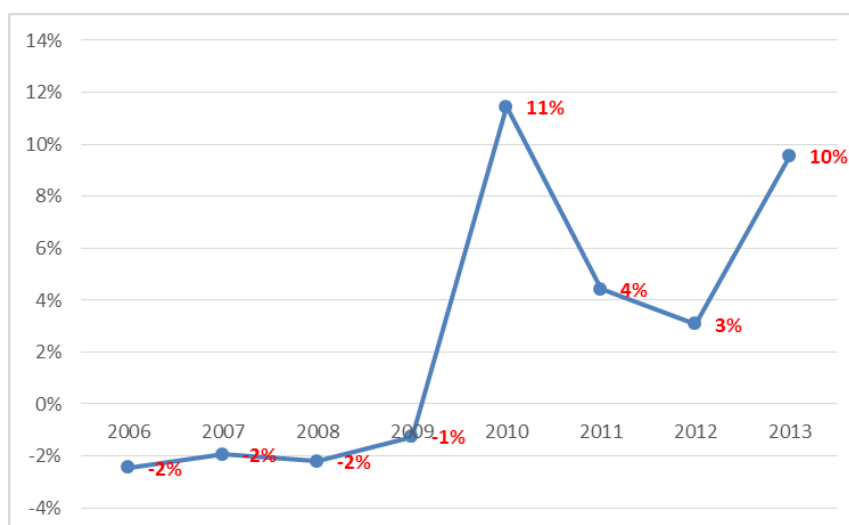
Figure 14: GHG Emission from Industrial wastewater treatment and discharge, 2005-2013

²⁴ Total annual volume of wastewater generated (in cubic meters) is estimated based on the industrial production (in tonnes) and the unit wastewater generation per tonne of product (cubic meters/tonne) based on the methodology outlined in the 2006 IPCC Guidelines for National GHG Inventories, Vol.5, Chapter 6 - Wastewater treatment and discharge, Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf



(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

Figure 15: Year-on-Year Variation Observed in Industrial Wastewater GHG emissions, 2005-2013



(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

It is observed that the contribution of the Pulp and Paper sector to GHG emissions from industrial wastewater treatment is the highest. The cumulative percent change in emissions in 2013 over the 2005 baseline values along with corresponding increase in industrial production, for each industry sector is given in Table 6. Available information on Pulp and Paper sector based on a CSE study indicates that wastewater generation in the Pulp and Paper sector has reduced, at an average annual rate of 7.4%²⁵. The impact of reduced wastewater generation on GHG emissions is evident for the Pulp and Paper sector, wherein GHG emissions have increased by 16% cumulatively between 2005 and 2013. It is much lower than the 103% increase recorded in industrial production over this period. Due to unavailability of latest year-on-year values for wastewater generation per unit of product, constant values are used for the other industry sectors in this assessment (see section 3.6.2 for more details). Use of constant value for other industry sector results in limitations in

²⁵ CSE Paper Industry Report, 2013. Available at <http://ipma.co.in/wp-content/uploads/2015/11/CSE-Paper-Industry-Report-2013.pdf>

estimations as it restricts capturing impacts of improvements in process and technology on wastewater generation and GHG emissions. Thereby, growth in estimated GHG emission matches the corresponding increase in industrial production for the industry sectors other than Pulp and Paper.

Table 6: Change in Industrial Production and Wastewater emission by industry sector, 2005-2013

INDUSTRY SECTOR ²⁶	INCREASE IN PRODUCTION IN 2013 OVER 2005	INCREASE IN GHG EMISSIONS IN 2013 OVER 2005 BASELINE
Beer	354%	354%
Coffee	12%	12%
Tannery	19%	19%
Sugar	39%	39%
Fertilizers	5%	5%
Meat	173%	173%
Dairy	42%	42%
Soft drink	-8%	-8%
Pulp & Paper	103%	16%

(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

It is noted that the Pulp & paper, Coffee, Soft drink, Meat and Tannery sectors, are ones with the highest GHG emission per tonne of product or per unit volume of treated wastewater. The critical industrial sectors having high specific CH₄ emission are given below in Table 7.

Table 7: Average industrial wastewater GHG emission per tonne of product and per m3 of wastewater generated for Industrial Sectors in India (2005-2013)

INDUSTRY SECTOR ²⁶	GHG EMISSION PER TONNE OF PRODUCT (KG OF CO ₂ e)	GHG EMISSION PER M ³ OF WASTEWATER GENERATED (KG OF CO ₂ e)
Coffee	189.0	37.8
Soft drink	139.9	37.8
Pulp & Paper	1,749.5	24.8
Meat	201.5	17.2
Tannery	104.2	3.3
Fertilizers	25.2	3.1
Sugar	3.1	3.1
Beer	27.4	3.0
Dairy	7.1	2.4

(Source: Analysis based on GHG Platform India – Phase II: 2005 – 2013 National Estimates – 2017 Series)

²⁶ In the assessment, the condition of the prevalent aerobic type wastewater treatment systems for Iron & Steel, Petroleum and Rubber industries is assumed to be well managed, and thereby these systems have Methane Correction Factor value of zero and thereby an emission factor value of zero (based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories), thereby leading to no CH₄ emissions from wastewater treatment. Thus, the Iron & Steel, Petroleum and Rubber sectors are not included in the Table.

3 Waste Sector

3.1 Overview of the sector

Waste management activities such as collection, treatment and disposal of solid waste and wastewater lead to GHG emission in the form of CH₄ and N₂O. Waste sector emissions are a result of the degradation of organic material under anaerobic conditions. Under the reporting structure of the 2006 IPCC Guidelines for National GHG inventories, key sources of GHG emission in the Waste sector include 4A solid waste disposal, 4D1 domestic wastewater treatment and discharge and 4D2 industrial wastewater treatment and discharge.

- Total emissions from the Waste sector in India in the year 2013 were 89.14 mil. tonnes of CO₂e, an increase of 36% (or 23.52 mil. tonnes of CO₂e) from 2005.
- Within the sector, domestic wastewater treatment and discharge emissions grew by 36% or 14.20 mil. tonnes of CO₂e for the period and contributed to 59.7% (53.24 mil. tonnes of CO₂e) of waste sector emissions for year 2013.
- GHG emissions from industrial wastewater treatment and discharge in 2013 were 21.03 mil. tonnes of CO₂e, contributing to 23.6% of the total Waste sector emissions. The industrial wastewater related emissions increased by 21% or 3.71 mil. tonnes of CO₂e during the period.
- Solid waste disposal contributed to GHG emission of 14.86 mil. tonnes of CO₂e in the year 2013, accounting for 16.7% of the Waste sector emissions. The emissions from solid waste disposal have increased by 61% (an absolute increase of 6.31 mil. tonnes of CO₂e) from 9.25 mil. tonnes of CO₂e in the base year 2005.

Table 8: Gas-wise GHG emission for the Source Categories in the Waste sector, 2013

IPC C ID	GHG SOURCE AND SINK CATEGORIES	CH ₄ (MIL. TONNES CH ₄)	N ₂ O (MIL. TONNES N ₂ O)	CO ₂ e ² (MIL. TONNES) BASED ON GWP VALUES FROM IPCC SECOND ASSESSMENT REPORT ³	CO ₂ e (MIL. TONNES) BASED ON GWP VALUES FROM IPCC FIFTH ASSESSMENT REPORT ⁴
4.	Waste	3.38	0.06	89.14	110.17
4A	Solid Waste Disposal	0.71		14.86	19.82
4A2	Unmanaged Waste Disposal Sites	0.71	-	14.86	19.82
4D	Wastewater Treatment and Discharge	2.67	0.06	74.28	90.35
4D1	Domestic Wastewater Treatment and Discharge	1.67	0.06	53.24	62.30
4D2	Industrial Wastewater Treatment and Discharge	1.01	-	21.03	28.05

3.2 Boundary of GHG estimates

The geospatial boundary of National-level GHG emission estimates for the Waste sector is the whole of India spanning a geographical area of 3.28 million sq. km. India houses a population of 1.2 billion as per Census 2011. It is the seventh largest country by area and second largest by population holding about 18% of the world's population. India lies between latitudes 8° N & 36° N and longitudes 66° E & 98° E²⁷

Based on estimates of the Central Statistics Office, India's GDP (at constant 2011-12 prices) in the year 2015-16 stood at INR 136,753,310 million, with economy expanding at 7.2% in 2014-15 and 7.6% in 2015-16²⁸. Economic development has implications on the Waste sector— with growing urbanization, economic activity, improved standards of living and disposal incomes impacting consumption patterns, waste composition, and

²⁷ India's Second National Communication to the United Nations Framework Convention on Climate Change, Available at: <http://unfccc.int/resource/docs/natc/indnc2.pdf>

²⁸ Based on CSO data indicated in KPMG (2016): India Economic Survey 2015-16 – Key Highlights. Available at <https://home.kpmg.com/content/dam/kpmg/in/pdf/2017/01/KPMG-Flash-News-India-Economic-Survey-2015-16%E2%80%93Key-Highlights-3.pdf>

leading to higher rates of waste generation²⁹. The diversity across the country is also reflected in the Waste Sector in terms of the quantum of waste and wastewater generation, its characteristics, and management.

3.3 Overview of Source Categories and Methodology

The emission estimates for the Waste sector in this assessment include emissions from the following source categories and sub-categories:

- 4A Solid waste disposal:
 - 4A2 Unmanaged Waste Disposal Sites
- 4D Wastewater treatment and discharge:
 - 4D1 Domestic Wastewater Treatment and Discharge
 - 4D2 Industrial Wastewater Treatment and Discharge

4A Solid waste disposal: CH₄ emissions from solid waste disposal depend on the amount and composition of the waste disposed into solid waste disposal sites and the condition of the disposal sites.

- Given that scientific waste disposal practices and landfill facilities are lacking in India, the sub-category '4A2 Unmanaged waste disposal sites' is appropriately selected to represent the prevalent unmanaged waste disposal in the Indian context.
- Given that during the reporting period, an insignificant quantum of waste is disposed in scientifically designed and managed waste disposal sites, the source category of '4A1: Managed waste disposal sites' is not yet applicable in the Indian context and therefore not considered in the present estimation.
- It is widely acknowledged and is corroborated from reports³⁰ that the prevalent mode of waste disposal is in unmanaged open disposal sites and hence 4A3: Uncategorized waste disposal sites' is also not considered.
- The scope of emission estimation from solid waste disposal is limited to the urban areas within India given that rural areas lack the requisite waste management and disposal systems and thereby GHG emission generation can be insignificant in the absence of controlled/semi-controlled anaerobic conditions, in line with India's Second National Communication and Biennial Update Report 2010.

4D Wastewater treatment and discharge: Treatment and discharge of wastewater in anaerobic conditions also releases significant amount of CH₄ emissions. N₂O emission is also produced by bacteria (denitrification and nitrification) in wastewater treatment and discharge.

- This emission source category is further divided into two sub-categories, namely '4D1 Domestic wastewater treatment and discharge' and '4D2 industrial wastewater treatment and discharge'.
- CH₄ and N₂O emissions from domestic wastewater due to treatment and discharge of liquid waste and sludge from housing and commercial sources, through various systems such as centralised sewage systems, open pits/ latrines, anaerobic lagoons, anaerobic reactors, and direct discharge into surface waters are included under sub-category 4D1 in the emission estimates.
- CH₄ emissions from industrial wastewater due to treatment and discharge of liquid wastes from industrial processes in 12 industry sectors are included under sub-category 4D2 in the emission estimates.

Emissions from the categories '**4B Biological treatment of solid waste**' and '**4C Incineration and open burning of waste**' are not included in the estimates due to the lack of reliable activity data for these categories and the absence of considerable number of waste incineration and composting facilities within the reporting period.

The emission estimation for the solid waste disposal is based on a combination of IPCC Tier I and Tier 2 approaches. Emissions related to treatment and discharge of both domestic and industrial wastewater is largely based on Tier I approach due to limited availability of country-specific data and emission factors for these sources. Where reliable country-specific data was not available, IPCC default values have been used and

²⁹ World Bank (2012): Urban Development Series Knowledge Papers: What a Waste- A Global Review of Solid Waste Management. Available at https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf

³⁰ ADB (2009): Project Document on 'Best Practices for Municipal Solid Waste Management in South Asia: A New Knowledge Product'. Available at <https://www.adb.org/sites/default/files/project-document/63293/40124-reg-spr-09.pdf>

appropriate assumptions have been used to close data gaps. Further details of methodological approach and data sources for the source categories considered in the estimates are provided in the following sections.

3.4 4A2 Unmanaged Waste Disposal Sites

3.4.1 Category Description

When solid waste is disposed in landfills or in dumpsites and in the presence of anaerobic conditions, the methanogenic bacteria break-down the degradable organic component in the waste, releasing CH₄ emissions. Decomposition of the organic content occurs slowly and the CH₄ emissions from a given mass of solid waste deposited continue to be released over a period spanning a few decades.

This assessment covers the disposal of municipal solid waste, which is generally defined as waste collected by local municipal governments or other local authorities, typically including residential, commercial, and institutional waste, street sweepings, and garden and park waste in either solid or semi-solid form (excluding industrial, hazardous, bio-medical and e-waste).

Industrial waste and other waste such as clinical waste and hazardous waste are not considered in the emission estimation, given the lack of reliable information for these waste streams and in accordance with India's Second National Communication Report¹². Furthermore, as indicated previously, disposal of municipal solid waste in rural areas is not included in the estimation since decomposition of rural waste occurs largely in the absence of anaerobic conditions and thereby does not lead to significant CH₄ emission generation.

Systematic and scientific disposal of waste is lacking in most of the Indian cities. The landfill sites are not properly constructed, and operation and maintenance of the landfill is inadequate as well. Most of the disposal sites are thereby unmanaged and are generally observed to be shallow¹⁷. This is also in consonance with India's Second National Communication¹². Therefore, the source category '4A2: Unmanaged waste disposal sites' is considered for emission estimation from solid waste disposal in India.

Secondary activity data obtained from key governmental organizations and research institutes including the CPCB, the CPHEEO, and NEERI has been primarily used in this assessment. The activity data used is of medium quality as data has been extrapolated using specific data sets and appropriate assumptions have been used to address data gaps.

Table 9: Principal Sources and Quality of Data for Solid Waste Disposal Estimates

IPCC ID	GHG SOURCE & SINK CATEGORIES	TYPE	QUALITY	SOURCE
4	Waste			
4A	Solid Waste Disposal			
4A2	Unmanaged Waste Disposal Sites	Secondary	Medium	CPCB, NEERI, CPHEEO

A combination of country specific emission factors and default values for coefficients as per the 2006 IPCC Guidelines have been used in the estimations across the reporting period. The emission factors and assumptions have largely been sourced from India's Second National Communication¹², relevant publications from NEERI³¹, and the 2006 IPCC Guidelines for National GHG Inventories¹⁵, in this order of preference, to prioritize the use of country specific emission factors and parameters (see the section 3.4.2 on methodology for further details on assumptions and emission factors used).

An assessment of the quality of activity data and emission factors used in the estimation is indicated in the Table 10 below. The quality has been assessed based on the source of the data and its availability. Published data sourced from government institutions and agencies is deemed to be of 'high' quality for the years where such published data is available. For years wherein, no data has been published for the parameter, the quality is assigned as 'low', with suitable assumptions used to address data gaps in such cases. Emission factors and default values sourced from the 2006 IPCC Guidelines for National GHG Inventories¹⁵ have been assessed to be of 'high' quality.

- Data and trends from Census of India, 2001 and Census of India, 2011 has been used for population estimates and therefore, the quality of data is considered as 'high' across all years.
- Published data relating to mass of waste deposited (i.e. waste generation, processing and disposal) from NEERI, CPCB and India's Second National Communication is available for the years 2005 and

³¹ Data sources for all parameters for solid waste disposal are indicated further in section 3.4.2 of this note.

2007. Therefore, the quality for the activity data on mass of waste deposited³² is assessed to be 'High' for these years and 'low' for the rest of the years wherein information is not available.

- The degradable organic carbon (DOC) content is a key parameter for emission estimation using the FOD model and its value depends on the waste composition. The DOC content has been estimated using available secondary waste composition data from a NEERI and CPCB study in 2005 and the data quality is deemed to be 'high'. Since, reliable data on waste composition is not available for the rest of the years, the data is assessed to be of 'low' quality.
- Values for the other emission factors and related parameters are sourced from the 2006 IPCC Guidelines for National GHG Inventories¹⁵. Therefore, the quality is assessed to be 'high' across the emission estimation period.
 - Fraction of Degradable Organic Carbon which decomposes (DOC_f)
 - Methane Correction Factor (MCF)
 - Fraction of CH₄ in generated landfill gas (F)
 - Oxidation factor (OX)
 - Methane Recovery (R)
 - Reaction constant (k)

Table 10: Qualitative Assessment of Year-wise Activity and Emission Factor Data used in the Solid Waste Disposal Estimates

S. No.	DATA/EMISSION FACTOR	QUALITY									
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	Activity Data										
	Population	H	H	H	H	H	H	H	H	H	H
	Mass of Waste deposited (W)	H	L	H	L	L	L	L	L	L	L
2	Emission Factors										
	Degradable Organic Carbon (DOC)	H	L	L	L	L	L	L	L	L	L
	Fraction of Degradable Organic Carbon which Decomposes (DOC _f)	H	H	H	H	H	H	H	H	H	H
	Methane Correction Factor (MCF)	H	H	H	H	H	H	H	H	H	H
	Fraction of CH ₄ in generated landfill gas (F)	H	H	H	H	H	H	H	H	H	H
	Oxidation factor (OX)	H	H	H	H	H	H	H	H	H	H
	Methane Recovery (R)	H	H	H	H	H	H	H	H	H	H
	Reaction constant (k)	H	H	H	H	H	H	H	H	H	H

Notes: H- high, L-low

3.4.2 Methodology

The overall methodology followed for solid waste disposal emission estimates is a mix of Tier 1 and Tier 2 approach. A top-down approach is followed in the collection of secondary activity data and estimation of CH₄ emissions from solid waste disposal.

Table 11: Type of Emission Factor and Level of Methodological Tiers adopted for Solid Waste Disposal Estimates

IPCC ID	GHG SOURCE & SINK CATEGORIES	CH ₄	
		METHOD APPLIED	EMISSION FACTOR
4A2	Unmanaged Waste Disposal Sites	T1, T2	D, CS

Notes: T1: Tier 1; T2: Tier 2; CS: Country-specific; D: IPCC default

³² Time series data on mass of waste going to disposal sites for the 50 years before 2005 is not available at the national-level. Therefore, it becomes necessary to estimate the total waste generated using data on urban population and the per capita waste generation and subsequently work out the extent of generated waste that is dumped in disposal sites based on information on waste processing.

The FOD model outlined in the 2006 IPCC Guidelines for National GHG Inventories¹⁵ to estimates emissions from decomposition of solid waste in waste disposal sites over a period of time is used in this assessment. The FOD model considers that waste deposited in a disposal site at a point of time decomposes gradually over time and the residual waste (material that remains after the partial decomposition of waste during anaerobic digestion process) continues to undergo anaerobic digestion again and generate CH₄ over a subsequent period of time (around 50 years). CH₄ emission will be generated until the waste deposited in the disposal site decomposes completely and reaches its full methane generation potential. The FOD model estimates the actual methane generation at a given point of time, accounting for the total methane generation over a preceding time period. The CH₄ generation potential of the waste that is disposed in a certain year will decrease gradually throughout the following decades. In this process, the release of CH₄ from this specific amount of waste decreases gradually.

As per the 2006 IPCC Guidelines and India's Second National Communication, the following equations are used to estimate CH₄ emission from Solid waste disposal³³:

CH₄ EMISSION FROM SOLID WASTE DISPOSAL SITES

$$CH_4 \text{ Emissions} = [\sum CH_4 \text{ generated}_T - R_T] * (1 - OX_T)$$

CH ₄ Emissions	= CH ₄ emitted in year T, Gg
T	= inventory year
x	= waste category or type/material
R _T	= recovered CH ₄ in year T, Gg (default value of 0 ³⁴)
OX _T	= oxidation factor in year T, (fraction) (default value of 0 ³⁵)

The amount of CH₄ formed from decomposable material is found by multiplying the CH₄ fraction in generated landfill gas and the CH₄/C molecular weight ratio (16/12).

CH₄ GENERATED FROM DECAYED DDOC_m

$$CH_4 \text{ generated}_T = DDOC_{m \text{ decomp}_T} * F * 16/12$$

Where,

CH ₄ generated _T	= amount of CH ₄ generated from decomposable material
DDOC _{m decomp_T}	= Decomposable Degradable Organic Carbon decomposed in year T, Gg
F	= fraction of CH ₄ , by volume, in generated landfill gas (fraction) (default value of 0.5 ¹⁵)
16/12	= molecular weight ratio CH ₄ /C (ratio)

The basis for the calculation is the amount of decomposable degradable organic carbon (DDOC_m). DDOC_m is the part of the organic carbon that will degrade under the anaerobic conditions in the solid waste disposal site.

It equals the product of the mass of waste deposited (W), the fraction of degradable organic carbon (DOC) in the waste, the fraction of the degradable organic carbon that decomposes under anaerobic conditions (DOC_f), and the part of the waste that will decompose under aerobic conditions (prior to the conditions becoming anaerobic) in the solid waste disposal site, which is interpreted with the methane correction factor (MCF).

DECOMPOSABLE DOC FROM WASTE DISPOSAL DATA³⁶

$$DDOC_m = W * DOC * DOC_f * MCF$$

Where,

DDOC _m	= mass of decomposable DOC deposited, Gg
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³³ As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Page 3.19.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

³⁴ As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Section 3.2.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

³⁵ As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.2.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

³⁶ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.2.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

W	= mass of waste deposited, Gg
DOC	= degradable organic carbon in the year of deposition, fraction, Gg C/Gg waste
DOC _f	= fraction of DOC that can decompose (fraction) (Default value of 0.5 ¹⁵)
MCF	= CH ₄ correction factor for aerobic decomposition in the year of deposition (fraction) (default value of 0.4 ³⁷)

The DOC in bulk waste is estimated based on the composition of waste and can be calculated from a weighted average of the degradable carbon content of various components (waste types/material) of the waste stream. The following equation estimates DOC using default carbon content values:

ESTIMATED DOC USING DEFAULT CARBON CONTENT VALUES³⁸

$$DOC = \sum_i (DOC_i * W_i)$$

Where,

DOC	= fraction of degradable organic carbon in bulk waste, Gg C/Gg waste
DOC _i	= fraction of degradable organic carbon in waste type i
W _i	= fraction of waste type i by waste category

The default DOC values for various fractions in MSW are given in Table 12. Since Plastics, Glass and Metals do not contain degradable organic carbon they have DOC value as zero.

Table 12: Default DOC content of different MSW components

MSW COMPONENT	DOC CONTENT IN PERCENT OF WET WASTE	DOC CONTENT IN PERCENT OF DRY WASTE
Paper/cardboard	40%	44%
Textiles	24%	30%
Food waste	15%	38%
Wood	43%	50%
Garden and Park waste	20%	49%
Nappies	24%	60%

(Source: 2006 IPCC Guidelines for National GHG Inventories, Vol. 5, Chapter 2, Table 2.6)

With a first order reaction, the amount of product is always proportional to the amount of reactive material. This means that the year in which the waste material was deposited in the disposal site is irrelevant to the amount of CH₄ generated each year. It is only the total mass of decomposing material currently in the site that matters.

DDOC_m ACCUMULATED IN THE SWDS AT THE END OF YEAR T³⁹

$$DDOC_{maT} = DDOC_{mdT} + (DDOC_{maT} - 1 * e^{-k})$$

DDOC_m DECOMPOSED AT THE END OF YEAR T⁴⁰

$$DDOC_{mdecompT} = DDOC_{maT} - 1 * (1 - e^{-k})$$

Where,

T	= inventory year
DDOC _{maT}	= DDOC _m accumulated in the SWDS at the end of year T, Gg
DDOC _{maT-1}	= DDOC _m accumulated in the SWDS at the end of year (T-1), Gg
DDOC _{mdT}	= DDOC _m deposited into the SWDS in year T, Gg
DDOC _{m decompT}	= DDOC _m decomposed in the SWDS in year T, Gg

³⁷ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Table 3.1.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

³⁸ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.7.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

³⁹ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.4.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

⁴⁰ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.5.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

k = reaction constant,

$$k = \ln(2)/t_{1/2} (y-l) = 0.17^{41}$$

$t_{1/2}$ = half-life time (y)⁴²

Data Sources and Assumptions

1. Population

The urban population of India is estimated based on population data and decadal population growth trends for the preceding 50-year time-period between the years 1954-2004 and for the reporting period of 2005-2014 as per the Census of India, 2001 and Census of India, 2011 respectively.

2. Mass of Waste deposited (W)

The FOD method assumes that carbon in waste decays gradually for decades to produce CH₄ emission. As per India's Second National Communication, it takes about 50 years for CH₄ emissions to come down to insignificant levels. Hence, it is necessary to estimate or collect 50-year data on waste disposal prior to the base year 2005 i.e. from 1954-2004.

Since time series data on waste disposal for the 50-year period before 2005 is not available for India, the historical waste generation is estimated based on urban population and per capita waste generation. Annual growth rates of per capita waste generation are calculated based on the decadal daily per capita waste generation rates available for India over the 50 years preceding 2005 as shown in Table 13. These annual growth rates are consistent with other publications⁴³ which indicate a growth rate of 1.3% per annum.

Table 13: Decadal daily Per capita Waste generation and Annual growth rates

YEAR	DAILY PER CAPITA WASTE GENERATION (KG/DAY) ⁴⁴	ESTIMATED ANNUAL PER CAPITA WASTE GENERATION BASED ON DAILY PER CAPITA WASTE GENERATION (KG/ANNUM)	ANNUAL GROWTH RATE ⁴⁵
1951	0.305	111.33	1.15%
1961	0.340	124.10	1.03%
1971	0.375	136.88	1.47%
1981	0.430	156.95	0.70%
1991	0.460	167.90	1.22%
2007	0.550	197.1	1.22% ⁴⁶

As per India's Second National Communication¹², it is assumed that only 70% out of the total waste generated reaches the disposal sites and CH₄ emissions resulting from its decomposition under anaerobic conditions are estimated.

3. Degradable Organic carbon (DOC)

The DOC value depends on the composition of waste. India's Second National Communication¹² uses an aggregated DOC value of 0.11 which is based on an assumed composition of solid waste in India. However, the composition of waste is changing over time as seen from waste composition data available for three different

⁴¹ As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

⁴² As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.4.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

⁴³ The CPHEEO, Ministry of Urban Development, GoI (2016): Manual on Municipal Solid Waste Management-2016, Part II: The Manual. Available at http://cpheeo.nic.in/WriteReadData/Cpheeo_SolidWasteManagement2016/Manual.pdf

⁴⁴ TERI (1998): Looking Back to Think Ahead: Green India 2047'. The publication includes per capita waste generation data from NEERI and CPCB which has been used for 19,511,991. The per capita waste generation for 2007 is based on India's Second National Communication Report which is available at: <http://unfccc.int/resource/docs/natc/indnc2.pdf>

⁴⁵ Annual Growth rates have been estimated based on per capita generation rates reported for certain years as given in the Table 13 and have been used in the emission estimation to calculate per capita generation rates for the intervening years.

⁴⁶ The annual growth rate of 1.2% estimated based on data for 1991 and 2007 has been used to calculate per capita generation rates from 2005-2014.

years (1971, 1995 and 2005) from studies conducted by the CPCB and NEERI (see Table 14). Since DOC is dependent on waste composition, the DOC value will also change over the years and should be factored into the estimation.

Since data on waste composition is not available across 50 years, the waste composition across the three years of 1971, 1995 and 2005 is assumed to be applicable for adjacent time periods i.e. 1954-1994, 1995-2004 and 2005-2014 (see Table 14). Using the default values for DOC content (see Table 12) for the degradable fractions in waste, the DOC values for the organic portion of the waste are calculated for the time periods 1954-1994, 1995-2004 and 2005-2014 as shown in Table 14.

Table 14: Estimated Degradable Organic Content using Waste Composition

COMPONENT	WASTE COMPOSITION			DEFAULT DOC CONTENT VALUES (WET WASTE) IN PERCENT FROM TABLE 12 AS PER 2006 IPCC GUIDELINES ⁴⁷
	1971 ⁴⁸	1995 ⁴⁸	2005 ⁴⁹	
Paper	4.14%	5.78%	8.13%	40%
Rags	3.83%	3.5%	4.4%	24%
Compostable Matter	41.24%	41.8%	47.4%	15%
DOC Estimated for overall waste (in fraction)	0.088	0.094	0.114	
Applicable time-period considered for estimated DOC value	1954-1994	1995-2004	2005-2014	-

4. DDOC_m decomposed in year T (DDOC_{m decompT})

The DDOC_m (i.e. the Decomposable Degradable Organic Carbon) decomposed in the year T (DDOC_{m decompT}) depends on the DDOC_m deposited in the year T (DDOC_{mdT}), the DDOC_m accumulated at the end of year T (DDOC_{maT}) and DDOC_m accumulated at the end of the previous year (T-1) (DDOC_{maT-1}). It is assumed the DDOC_m accumulated in the initial year of the 50-year time period considered under the FOD model (i.e. 1954) is zero.

Using the values estimated for DDOC_m deposited and DDOC_m accumulated, the DDOC_m decomposed is calculated for all the years under 50-year time period from 1954-2004 and subsequently is used to estimate CH₄ emissions from 2005-2014.

3.4.3 Uncertainties

Uncertainties in the emission estimates from solid waste disposal result due to the following factors

- Limited reliable information on waste generation and disposal:** The FOD method used in the emission estimation, assumes that carbon in waste decays gradually for decades to produce CH₄ emission long after it is disposed and therefore, it is necessary to estimate or collect 50-year data on waste disposal prior to the base year 2005 i.e. from 1954-2004. Data on municipal solid waste generation and disposal rates is not available for the said period. The Municipal Solid Waste (Management and Handling) Rules, 2000⁵⁰ (amended recently in 2016⁵¹) and the Manual on Municipal Solid Waste Management Systems⁵² that lays down guidelines for urban local bodies to collect and treat solid waste first came into existence in the year 2000. As per the guidelines in the Rules, urban local bodies are mandated to report to the respective SPCB's and CPCB on the status of their waste generation and treatment rates. Given that a reporting mandate and mechanism was only established in the year 2000 under the ambit of the Municipal Solid

⁴⁷ As per 2006 IPCC Guidelines, Vol. 5, Chapter 2: Waste Generation, Composition and Management Data, Table 2.6. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

⁴⁸ Integrated Modeling of Solid Waste in India (March, 1999) CREED Working Paper Series no 26 and CPCB, 1999

⁴⁹ Data from NEERI and CPCB study in 2005 published in CPHEEO, Ministry of Urban Development, GoI (2016): Manual on Municipal Solid Waste Management-2016, Part II: The Manual, Figure 3.3.

Available at http://cpheeo.nic.in/WriteReadData/Cpheeo_SolidWasteManagement2016/Manual.pdf

⁵⁰ Available at <http://eprtnvis.nic.in/All%20PDF%20Files/LEGSLA/The-Municipal-Solid-Wastes-Management-and-Handling-Rules-2000.pdf>

⁵¹ Available at <http://www.moef.gov.in/sites/default/files/SWM%202016.pdf>

⁵² Available at <http://moud.gov.in/publication/manual-on-solid-waste-management-systems-cpheeo-2000.php>

Waste (Management and Handling) Rules, 2000, official datasets relating to solid waste generation and its management before this time are not available. Therefore, in absence of an official source of data before the year 2000, data from other sources have been used and interpolated. Even in the post-2000 period, year-on-year data on solid waste generation and disposal is not available. Given the lack of information, it is assumed that 70%¹² of the waste generated goes to the landfill across the period from 1954-2014, contributing to uncertainty in the estimates.

- **Functionality of treatment systems:** The available datasets on the treatment rates are presently based on the capacity of the processing plants existing in India. It does not consider the functionality of the plants. Several treatment plants in India are either non-operational or not working to full potential which is resulting in additional amount of waste going to landfill than the recorded values. Due to lack of consolidated datasets on the functionality of the waste treatment plants, it is difficult to factor the same in the estimations.
- **Limited data for DOC estimation:** The DOC estimation is a function of waste composition, which has changed over time and varies from region to region based on consumption patterns. Since regularly updated data on waste composition is not available across the period from 1954-2014, the waste composition data available across the three years of 1971, 1995 and 2005 is assumed to be applicable for adjacent time periods i.e. 1954-1994, 1995-2004 and 2005-2014. The corresponding DOC values have been estimated based on this intermittent waste composition data and applied across these three-time periods to calculate emissions. While waste composition may not change drastically, this approximation due to unavailability of reliable data contributes to a certain level of uncertainty in the estimates.

As per IPCC, uncertainty of GHG emissions from the disposal of solid waste based on activity data and emission factors are as follows⁵³:

- Total municipal solid waste generated: $\pm 30\%$ is a typical value for countries which collect waste generation data on a regular basis; for countries with poor quality data: more than a factor of two
- Fraction of municipal solid waste sent to solid waste disposal site: $\pm 30\%$ for countries collecting data on disposal at SWDS
- Total uncertainty of Waste Composition: $\pm 30\%$ for countries with country-specific data based on studies including periodic sampling
- Degradable Organic Carbon (DOC): $\pm 10\%$ for country-specific value and based on the experimental data over longer time periods
- Methane Correction Factor (MCF): $\pm 30\%$ for IPCC default value of 0.4
- Fraction of CH₄ in generated landfill gas: $\pm 5\%$ for IPCC default value of 0.5
- Methane Recovery: $\pm 50\%$ if metering is not in place.

Sensitivity Analysis for estimated DOC value

India's Second National Communication¹² uses an aggregated DOC value of 0.11 in the emission estimation for year 2007 which is based on an assumed composition of solid waste for India. However, the DOC value depends on the composition of waste and should change over the years with changing waste composition.

The present emission estimates factor in the impact of changing composition on the DOC value. A more realistic DOC value for the organic portion of the waste has been calculated using the default 2006 IPCC Guidelines for National GHG Inventories defined DOC content⁴⁷ for each of the constituent degradable fractions based on the changing waste composition over the three-time periods of 1956-1994, 1995-2004 and 2005-2014. This estimated country-specific DOC value has been considered and applied across these time periods of 1956-1994, 1995-2004 and 2005-2014 in the emission calculation.

An alternate scenario I has been considered that uses the DOC value of 0.11 as per India's Second National Communication¹² and to assess the deviation in emission from the considered estimates.

⁵³ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Table 3.5.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

Table 15: Alternate Scenario for DOC value in the Solid Waste Disposal Emission Estimates

TIME PERIODS	DOC- CONSIDERATION IN GHG PLATFORM INDIA FINAL EMISSION ESTIMATES	DOC – SCENARIO I
1954 – 1994	0.088	0.11
1995 – 2004	0.094	0.11
2005 – 2014	0.114	0.11

Table 16: Deviation in Solid Waste Disposal GHG emission results based on Sensitivity Analysis

YEAR	GHG PLATFORM INDIA FINAL EMISSION ESTIMATES (MIL. TONNES OF CO ₂ e)	SCENARIO I – PERCENT DEVIATION W.R.T. CONSIDERED EMISSION ESTIMATES
2005	9.25	17.8%
2006	10.02	13.0%
2007	10.76	9.5%
2008	11.47	6.7%
2009	12.16	4.6%
2010	12.85	2.9%
2011	13.52	1.6%
2012	14.18	0.6%
2013	14.86	-0.2%
2014	15.56	-0.9%

3.4.4 Source Category specific QA/QC

The internal QC procedures outlined previously in 'GHG estimation preparation, data collection, process and storage' in section 1.3 are carried out for this source category. Specific considerations for the solid waste disposal category, in view of the emission estimation approach, are indicated below. Discussions were conducted with experts from CPCB and NEERI over the datasets available for solid waste, for state-level waste generation and waste processing. These discussions contributed towards selection of year 2005 data as basis to estimate waste generation and towards assumptions for estimating proportion of waste going to landfill.

The FOD model for emission estimation from solid waste disposal considers historical disposal of solid waste (from year 1995 onwards). Since the solid waste generation and waste composition has changed over time, published country-specific data available for these two parameters across the period from 1955-2014 has been used in the emission estimation. The country-specific per capita MSW generation value for each of the years between 2005-2013 used in this assessment has been compared against the default IPCC value of 0.12 tonnes/capita/year⁵⁴ to check that this falls within the IPCC specified uncertainty range of factor of 2 for MSW generation⁵⁵. The DOC value of 0.114 used for the period from 2005-2013 in this assessment has also been checked with the country-specific DOC value of 0.11 indicated in India's Second National Communication¹² and falls within the $\pm 10\%$ uncertainty range specified by IPCC for country-specific DOC values⁵⁵. These are therefore deemed to reasonably acceptable based on expert judgment of the authors of this note. The relevant data sources and the method used to apply this data across the years have been documented in the section 3.4.2 of this reporting document. Since this assessment is limited to solid waste disposal in urban areas, it is checked that the applied data and factors refer to the urban context as well and are deemed to be appropriate.

3.4.5 Recalculation

No recalculations in the emission estimates have been done for solid waste disposal.

3.4.6 Verification

An external verification of the emission estimates for this source category has not been undertaken at present. However, relevant QA/QC procedures have been applied internally to ensure reliability of calculations,

⁵⁴ As per IPCC 2006 Guidelines, Vol. 5, Chapter 2: Solid Waste disposal, Table 2A.1

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf

⁵⁵ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Table 3.5.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

processing of data, consistency, and transparent and clear documentation of methodology, assumptions and results. The emission estimates have undergone a peer review process and have been finalized subsequently.

The emission estimates for solid waste disposal under this assessment have also been compared with the estimates reported for year 2007 and 2010 in India's National communication documents – the Second National Communication 2012¹² and the First Biennial Update Report 2015¹³. The estimates for 2007 and 2010 show an under-estimation, with a deviation of 15.2% and 8.0% respectively as compared to the official estimates reported by India for solid waste disposal (see Table 17).

Table 17: Comparison of the GHG emission estimates for Solid Waste Disposal with Nationally Reported Values

YEAR	EMISSION ESTIMATES FOR SOLID WASTE DISPOSAL (MIL. TONNES OF CO ₂ e)	OFFICIAL EMISSION ESTIMATES FOR SOLID WASTE DISPOSAL AS PER SECOND NATIONAL COMMUNICATION (2007) AND BIENNIAL UPDATE REPORT (2010) (TONNES OF CO ₂ e)	PERCENT DEVIATION W.R.T. OFFICIAL EMISSION ESTIMATES
2007	10.76	12.69	-15.2%
2010	12.85	13.96	-8.0%

The possible reasons for deviation from the officially reported emissions are discussed below:

- **Variation in per capita waste values:** To accurately account for accumulated DOC and potential CH₄ emission generation from historic solid waste disposal, the FOD model suggests that emission estimations be done for a 50-year period preceding the initial year of emission estimation (i.e. year 2005 in this assessment). Since historic time-series data on waste disposed in solid waste disposal sites is not available, the waste disposal is estimated based on population and per capita generation. India's Second National Communication¹² indicates a value of 0.55 kg/day/capita for the average per capita waste generation rate for year 2007. The Second National Communication¹² and the Biennial Update Report¹³ do not provide details of the per capita generation values that are used in the estimations of historic solid waste generation and subsequent calculation of Decomposable Degradable Organic Carbon (DDOCm). In this assessment, decadal per capita waste generation rates available from published secondary sources for one year in each of the five decades (1951-2005) (see Table 13) have been used to calculate the waste generation over the period of assessment. Likely variations in the per capita generation rates considered over the years (for which values considered in the case of official National GHG emission estimates are unknown) contribute to the deviation in the two estimations.
- **Variation in DOC values:** India's Second National Communication¹² indicate that a DOC value of 0.11 is used in the emission estimation, which is an aggregate DOC value based on an assumed composition of solid waste for India. The DOC value depends on the composition of waste and should change over the years with changing waste composition. This assessment factors in the impact of changing composition on the DOC value. A more realistic DOC value for the organic portion of the waste has been calculated for each of the constituent degradable fractions based on the changing waste composition over the three-time periods of 1956-1994, 1995-2004 and 2005-2012 (see Table 14). In the sensitivity analysis, emissions have been estimated by assuming a constant DOC value of 0.11 across the period of assessment (as per the National Communication) and this results in CH₄ emission of 11.78 Mil. tonnes of CO₂e and 13.22 Mil. tonnes of CO₂e for year 2007 and 2010 respectively – values which are relatively closer to emissions reported in the Second National Communication¹² and the Biennial Update Report¹³. However due to the reasons indicated above, our assessment factors in changing waste composition over time and uses varying values of DOC over time in the final emission estimates.
- **Urban population:** The Urban population used in this assessment to calculate the total waste generated and disposed in the emission reporting period 2005-2013 and for the fifty years preceding 2005 is based on population data and decadal growth trends as per the information reported by the Census of India. The Second National Communication¹² and the Biennial Update Report¹³ do not provide details of the urban population figures that are used in the estimations across the years. Possible variation in the methods used to arrive at urban population can be a likely source of deviation.

3.4.7 Planned improvements

Historical data on municipal solid waste generation and disposal is not available. Reliable and year-on-year data on municipal solid waste generation, waste composition for the past decade is lacking as well with inconsistencies observed in reported data available from different sources. Thereby, reliable data is sought on waste generation and the changing composition of waste in the country. This will limit the need for approximations and assumptions and improve accuracy of the emission estimates.

Inconsistent and inaccurate reporting in datasets on waste processing/treatment and the proportion of waste going to landfill is a challenge. Reporting of waste treatment rates is largely done based on the installed capacities of the processing plants and does not account for operational status (non-operational/ low capacity utilization) and therefore the volume of waste going to landfill cannot be assessed accurately. Thereby, how well the processing plants are operating and any impacts of improved waste treatment over time cannot be factored into the estimates. Improved data on these aspects is sought to improve accuracy of estimation and capture corresponding emission reductions.

Going forward, the GHG Platform India could look at including activities to collect primary data on solid waste and waste processing, to some extent, to improve reliability of the estimates. The Platform could help promote and provide technical inputs towards recording and reporting of relevant activity data in an accurate, consistent and transparent manner. The Platform could also engage further with the Ministry of Environment, Forests and Climate Change to gain access to the underlying datasets and assumptions used for the official National GHG emission estimates. This will greatly help in improving the accuracy of this assessment, enable better comparability, and help identify and address any limitations in the solid waste estimates prepared under this assessment as well as official emission estimates.

3.5 4DI Domestic Wastewater Treatment and Discharge

3.5.1 Category Description

Domestic wastewater includes human sewage mixed with other household wastewater, which can include effluent from shower drains, sink drains, washing machines, etc. This source category refers to CH₄ and N₂O emissions generated due to the treatment and discharge of domestic wastewater. CH₄ emissions are generated from domestic wastewater on its treatment (on site through septic tanks, connected by sewer network to a centralized treatment plant) or untreated disposal via an outfall under anaerobic conditions⁵⁶. The extent of CH₄ emission from wastewater depends primarily on the quantity of degradable organic material in the wastewater, the volume of wastewater generated, and the type of treatment system used.

The characteristics of domestic waste water and consequently the associated GHG emissions vary from place to place depending on factors such as economic status, community food intake, water supply status, treatment systems and climatic conditions of the area. To account for these factors in the CH₄ emission estimation, the domestic wastewater is further categorized based on income group for urban and rural areas across India as follows in line with the 2006 IPCC Guidelines⁵⁶

- Urban high income
- Urban low income
- Rural

N₂O emission occurs from the degradation of the nitrogen present in domestic wastewater, which mainly results from human protein consumption. The degradation of nitrogen occurs on the disposal of domestic wastewater into waterways, lakes, or sea.

Secondary sources including published reports and studies of key governmental and research institutions such as the CPCB, the National Sample Survey Organization (NSSO), the Census of India, and the NEERI have been used to source country specific activity data in this assessment. Where the use of country-specific information is not feasible due to limitations in the data, IPCC defined default values have been used. The data is gauged to be of medium quality overall since data is available intermittently and the same has been applied across the reporting period.

⁵⁶ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Table 18: Principal Sources and Quality of Data for Domestic Wastewater Treatment and Discharge Estimates

IPCC ID	GHG SOURCE & SINK CATEGORIES	TYPE	QUALITY	SOURCE
4	Waste			
4D	Wastewater treatment and discharge			
4DI	Domestic wastewater treatment and discharge	Secondary	Medium	CPCB; Census of India; NSSO, NEERI

For the CH₄ emission estimates, the Census of India data for 2001 and 2011 has been used along with IPCC country default values to estimate the distribution of India's population into the three income groups –Urban high, urban low, and rural across the reporting period. For CH₄ emission estimates relating to urban domestic wastewater, IPCC default values on the distribution of different wastewater discharge/treatment systems has been supplemented with data from CPCB studies to adapt some of the IPCC default values to the Indian context. Data from the Census of India surveys has been used to work out the distribution of different wastewater discharge/treatment systems for the rural population. With regard to the estimates for N₂O emission from domestic wastewater, country specific values of the per capita protein intake have been used from NSSO surveys (see the section 3.5.2 on methodology for further details on assumptions, data sources and emission factors used).

An assessment of the quality of activity data and emission factors used in the estimation is indicated in the Table 19 below. The quality has been assessed based on the source of the data⁵⁷ and its availability. Published data sourced from government institutions and agencies is deemed to be of 'high' quality for the years where such published data is available. For years wherein no data has been published for the parameter, the quality is assigned as 'low', with suitable assumptions used to address data gaps in such cases. Emission factors and default values sourced from the 2006 IPCC Guidelines^{Error! Bookmark not defined.} have been assessed to be of 'high' quality.

- Population data is available for 2001 and 2011. Population estimates for the intermediate years' have been found using decadal growth rate trends and therefore the quality of data is considered as 'high' across all years.
- The per capita BOD values are sourced from NEERI data available for year 2007 and data quality for this parameter is thus assessed to be of 'high' quality for year 2007⁵⁸. For the rest of the years where data is not available, quality is assessed to be 'low'.
- The degree of utilization of treatment/discharge pathway or system for rural population is based on the Latrine facility dataset, Census of India. The data is available for 2001 and 2011 and is considered to be of 'high' quality for year 2011 within the emission estimation period and of 'low' quality for the rest of the years where data is unavailable. For urban population, the value of this parameter is sourced from the 2006 IPCC Guidelines for National GHG Inventories^{Error! Bookmark not defined.} and thus is considered to be of 'high' quality across the reporting period.
- The values of fraction of population in the income group (i.e. fraction of urban high-income, urban low-income and rural population) have been sourced through a combination of Census of India data for 2001 and 2011 and the 2006 IPCC Guidelines for National GHG Inventories^{Error! Bookmark not defined.}. Thus, the data quality is considered as 'high' for the reporting period.
- The annual per capita protein consumption value is available from NSSO surveys. The data is available for the years 2005, 2009 and 2011 for which data quality is considered 'high'. For the rest of the years, since data is unavailable the quality is assigned as 'low'.
- Values for the following parameters and emission factors are sourced from the 2006 IPCC Guidelines for National GHG Inventories^{Error! Bookmark not defined.}. Therefore, the quality is assessed to be 'high' across the emission estimation period.
 - Organic Component removed as Sludge in inventory year (S)
 - Correction factor for additional industrial BOD discharged into sewers (I)
 - Amount of CH₄ recovered in inventory year (R)
 - Maximum CH₄ producing capacity (B₀)
 - Methane correction factor (MCF_i)
 - Fraction of Nitrogen in Protein (F_{NPR})

⁵⁷ Data sources for all parameters for domestic wastewater are indicated further in section 3.5.2 of this note.

⁵⁸ The values are available for Bihar, Chandigarh, Delhi, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Uttar Pradesh, Uttarakhand and West Bengal. For rest of the States, the national average BOD values are used.

- Factor for Non-consumed protein added to the wastewater ($F_{\text{NON-CON}}$)
- Factor for Industrial and commercial co-discharged protein into the sewer system ($F_{\text{IND-COM}}$)
- Nitrogen removed with sludge (N_{SLUDGE})

Table 19: Qualitative Assessment of Year-wise Activity and Emission Factor Data used in the Domestic Wastewater Treatment and Discharge Estimates

Sr. No.	Activity Data/Emission Factor	Quality									
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	Activity data										
(a)	Population (P)	H	H	H	H	H	H	H	H	H	H
(b)	Per capita BOD in inventory year, g/person/day	L	L	H	L	L	L	L	L	L	L
(c)	Degree of utilisation of treatment/discharge pathway or system, j, for each income group fraction i (T_{ij}) – Rural	L	L	L	L	L	L	H	L	L	L
(d)	Degree of utilisation of treatment/discharge pathway or system, j, for each income group fraction i (T_{ij}) - Urban	H	H	H	H	H	H	H	H	H	H
(e)	Fraction of population in income group i (U_i)	H	H	H	H	H	H	H	H	H	H
(f)	Organic Component removed as Sludge, kg BOD/year (BOD)	H	H	H	H	H	H	H	H	H	H
(g)	Correction factor for additional industrial BOD discharged into sewers (I)	H	H	H	H	H	H	H	H	H	H
(h)	Amount of CH_4 recovered in inventory year (R)	H	H	H	H	H	H	H	H	H	H
(i)	Annual per capita protein consumption, kg/person/yr	H	L	L	L	H	L	H	L	L	L
2	Emission factors										
(a)	Maximum CH_4 producing capacity, kg CH_4 /kg BOD (B_o)	H	H	H	H	H	H	H	H	H	H
(b)	Methane correction factor (MCF_j)	H	H	H	H	H	H	H	H	H	H
(c)	Fraction of Nitrogen in Protein (F_{NPR})	H	H	H	H	H	H	H	H	H	H
(d)	Factor for Non-consumed protein added to the wastewater ($F_{\text{NON-CON}}$)	H	H	H	H	H	H	H	H	H	H
(e)	Factor for Industrial and commercial co-discharged protein into the sewer system ($F_{\text{IND-COM}}$)	H	H	H	H	H	H	H	H	H	H
(f)	Nitrogen removed with sludge (N_{SLUDGE})	H	H	H	H	H	H	H	H	H	H

Notes: H- high, L-low

3.5.2 Methodology

The overall methodology followed for domestic wastewater related CH_4 emission estimates is consistent with the IPCC Tier I approach. For N_2O emission estimates, a Tier I approach has been largely followed with national average protein consumption values over the years used to estimate emissions. As indicated earlier, while most the activity data used is country specific, default values of the emission factors as per the 2006

IPCC Guidelines⁵⁶ have been used in the estimates for CH₄ and N₂O emission. A top-down approach is followed to estimate CH₄ and N₂O emission from domestic wastewater.

Table 20: Type of Emission Factor and Level of Methodological Tier adopted for Domestic Wastewater Treatment and Discharge Estimates

IPCC ID	GHG SOURCE & SINK CATEGORIES	CH ₄		N ₂ O	
		METHOD APPLIED	EMISSION FACTOR	METHOD APPLIED	EMISSION FACTOR
4DI	Domestic wastewater treatment and discharge	TI	D	TI	D

Notes: TI: Tier I; CS: Country-specific; D: IPCC default

A. CH₄ Emissions from Domestic Wastewater Treatment and Discharge

Calculation of CH₄ emission from treatment of domestic wastewater is largely based on the country population, degree of utilization of treatment system or discharge pathways relevant to urban high income, urban low income and rural residents respectively. The total organics in waste water determine the quantum of CH₄ emissions.

As per the 2006 IPCC Guidelines for National GHG Inventories⁵⁹ and India's Second National Communication¹², the following equation is used to estimate CH₄ emissions from domestic wastewater treatment and discharge

$$CH_4 \text{ Emissions} = \sum_{i,j} [(U_i * T_{i,j} * EF_j)](TOW - S) - R$$

Where,

CH₄ Emissions = Methane emissions in inventory year, kg CH₄/yr

TOW = total organics in wastewater in inventory year, kg BOD/yr

S = organic component removed as sludge in inventory year, kg BOD/yr (default value of 0⁶⁰)

U_i = fraction of population in income group i in inventory year

T_{i,j} = degree of utilization of treatment/discharge pathway or system j, for each income group fraction i in inventory year

i = income group: rural, urban high income and urban low income

j = each treatment/discharge pathway or system

EF_j = emission factor, kg CH₄ / kg BOD

R = amount of CH₄ recovered in inventory year, kg CH₄/yr (default value of 0⁶¹)

The emission factor EF_j is applicable for the various type treatment system or discharge pathways based on the corresponding MCF values as listed in Table 20. It is a function of the maximum CH₄ producing potential (B₀) and the methane correction factor (MCF) for the waste water treatment and discharge system⁶². The MCF indicates the extent to which the CH₄ producing capacity (B₀) is realized in each type of treatment and discharge pathway and system.

$$CH_4 \text{ Emission Factor } EF_j = B_0 * MCF_j$$

Where,

EF_j = emission factor, kg CH₄/kg BOD

j = each treatment/discharge pathway or system

B₀ = maximum CH₄ producing capacity, kg CH₄/kg BOD (Default value 0.6⁶³)

⁵⁹ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.1.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

⁶⁰ As per 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6: Wastewater Treatment and Discharge.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

⁶¹ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge and NEERI document on Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, 2010. Available at: <http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf>

⁶² As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.2.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

⁶³ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.2.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

MCF_j = methane correction factor (fraction)

The default MCF values for different types of domestic wastewater treatment and discharge pathways as available in the 2006 IPCC guidelines⁶⁴ are given in Table 21.

Table 21: Default MCF values for Domestic Wastewater by treatment type and discharge pathway

TYPE OF TREATMENT AND DISCHARGE PATHWAY OR SYSTEM	DESCRIPTION	MCF
Untreated system		
Sea, river, and lake discharge	Rivers with high organic loadings can turn anaerobic	0.1
Stagnant sewer	Open and warm	0.5
Flowing sewer (open or closed)	Fast moving, clean. (Insignificant amounts of CH ₄ from pump stations, etc.)	0
Treated system		
Centralized, aerobic treatment plant	Must be well managed. Some CH ₄ can be emitted from settling basins and other pockets.	0
Centralized, aerobic treatment plant	Not well managed. Overloaded.	0.3
Anaerobic digester for sludge	CH ₄ recovery is not considered here.	0.8
Anaerobic reactor	CH ₄ recovery is not considered here.	0.8
Anaerobic shallow lagoon	Depth less than 2 metres, use expert judgment	0.2
Anaerobic deep lagoon	Depth more than 2 metres	0.8
Septic system	Half of BOD settles in anaerobic tank	0.5
Latrine	Dry climate, ground water table lower than latrine, small family (3-5 persons)	0.1
Latrine	Dry climate, ground water table lower than latrine, communal (many users)	0.5
Latrine	Wet climate/flush water use, ground water table higher than latrine	0.7
Latrine	Regular sediment removal for fertilizer	0.1

(Source: 2006 IPCC Guidelines, Vol.5, Chapter 6 Table 6.3)

A key parameter for this source category is the total amount of organically degradable material in the wastewater (TOW). This parameter is a function of human population and Biochemical Oxygen Demand (BOD)⁶⁵ content of waste water generated per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year).

The equation for TOW in domestic wastewater is⁶⁶:

$$TOW = P * BOD * 0.001 * I * 365$$

Where,

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = population in inventory year, (person)

BOD = country-specific per capita BOD in inventory year, g/person/day,

0.001 = conversion from grams BOD to kg BOD

I = correction factor for additional industrial BOD discharged into sewers

⁶⁴ As per 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

⁶⁵ The principal factor in determining the CH₄ generation potential of domestic wastewater is the amount of degradable organic material in the wastewater i.e. BOD content. Wastewater with higher BOD concentrations will generally yield more CH₄ than wastewater with lower BOD concentrations. Both the type of wastewater and the type of bacteria present in the wastewater influence the BOD concentration of the wastewater.

⁶⁶ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Data Sources and Assumptions

1. Population

The national, urban, and rural population of India is estimated based on population data and decadal population growth trends for the reporting period of 2005-2014 as per the Census of India, 2001 and Census of India, 2011.

2. Fraction of Population in income group i (U_i)

For domestic wastewater emission estimation, the 2006 IPCC Guidelines for National GHG Inventories categorize the population in urban and rural areas into three different income groups viz. urban high income, urban low income, and rural. As per the 2006 IPCC Guidelines for National GHG Inventories⁵⁶, the default country values for India for fraction of population in Urban high-income group is 0.06, that for the Urban low-income group is 0.23, and the fraction of rural population is 0.71 of the total country population.

Country specific data on the proportion of Urban and Rural population for India is available from the population estimates of Census of India for 2001 and 2011 and has been used in the emission estimation for the period 2005-2014⁶⁷ (see Table 22). However, the Census data does not provide information to estimate the distribution of Urban population into two income groups- Urban Low income and Urban High income as classified in the 2006 IPCC Guidelines for National GHG Inventories. Therefore, the same ratio of Urban high ($0.06/0.29 = 21\%$) and Urban low ($0.23/0.29 = 79\%$) population as per the default country values given in the 2006 IPCC Guidelines for National GHG Inventories⁵⁶ is applied to the Census of India data for 2001 and 2011 to further calculate the Urban high and low population distribution for these years (see Table 23).

Assumption: Since only decadal information on the share of Urban and Rural population is available from the Census of India, the proportion of Urban and Rural population as per Census of India 2001 and Census of India 2011 is assumed to be applicable for the two-time periods 2005-2010 and 2011-2013 respectively which cover the reporting period in the emission estimates.

Table 22: Share of Urban Population for India in 2001 and 2011

YEAR	SHARE OF URBAN POPULATION	SHARE OF RURAL POPULATION	SOURCE
2001	27.81%	72.19%	Census of India, 2001
2011	31.15%	68.85%	Census of India, 2011

Table 23: Estimation of Fraction of population in Urban high and Urban low-income group for 2001 and 2011

TIME PERIOD	FRACTION OF POPULATION IN INCOME GROUP: (U_i)			REMARKS
	URBAN HIGH	URBAN LOW	RURAL	
2005-2010	$(0.06/0.29) * 27.81\% = 0.06$	$(0.23/0.29) * 27.81\% = 0.22$	0.72	<u>Urban High and Urban low:</u> Estimated based on share of Urban population as per Census 2001 and distribution of Urban High income and Low-income groups in the Urban population as per 2006 IPCC Guidelines ⁵⁶ <u>Rural:</u> Estimated based on share of Rural population as per Census 2001
2011-2013	$(0.06/0.29) * 31.15\% = 0.06$	$(0.23/29) * 31.15\% = 0.25$	0.69	<u>Urban High and Urban low:</u> Estimated based on share of Urban population as per Census 2011 and distribution of Urban High income & Low-income groups in the Urban population as per 2006 IPCC Guidelines ⁵⁶ <u>Rural:</u> Estimated based on share of Rural population as per Census 2011

⁶⁷ For '4D1 Domestic wastewater treatment and discharge', the emission estimation has been undertaken for year 2014 as well since relevant data is available for this source category. However, to maintain consistency with regards to the emission accounting and reporting period across the Waste sector, the overall emissions reported in this document are limited to the period 2005-2013.

3. Degree of Utilization of treatment/discharge pathway or system j , for each income group fraction i (T_{ij})

The degree of utilization expresses the contribution or share (in terms of a fraction) of each discharge system in the treatment of all the wastewater generated by each income group. This is a key parameter since this relates to the proportion of the resident population using different wastewater treatment/discharge pathways or systems. For example, the degree of utilization rates listed for Urban High-Income group in Table 24 implies that of the total urban high-income population, 18% use on-site septic tanks, 8% use on-site latrines, 67% are served by sewer systems and 7% use systems other than these to discharge and treat their domestic wastewater.

Each of treatment/discharge pathways or systems will have different CH₄ emission factors (based on corresponding IPCC defined MCF values which are listed in Table 21); thereby having a varying contribution to the GHG emissions. The default values of degree of utilization rates specified in the 2006 IPCC Guidelines for Urban high income, urban low income, and rural population in India are given in Table 24. The Treatment/Discharge pathways or systems are broadly classified by the 2006 IPCC Guidelines⁵⁶ into collected systems (i.e. wherein wastewater is conveyed using a sewer network) and uncollected systems (wastewater not conveyed using a sewer network).

Table 24: Default India specific Degree of Utilization Rates for Domestic Wastewater Treatment/Discharge Pathways or Systems

INCOME GROUP	TREATMENT/DISCHARGE TYPE USED AS PER 2006 IPCC GUIDELINES	CLASSIFICATION OF THE SYSTEM AS PER 2006 IPCC GUIDELINES (COLLECTED/ UNCOLLECTED AND TREATMENT)	DEGREE OF UTILIZATION OF TREATMENT/ DISCHARGE PATHWAY OR SYSTEM j , FOR EACH INCOME GROUP FRACTION i (T_{ij})
Urban High Income	Septic Tank	Uncollected (Treatment on-site)	0.18
	Latrine	Uncollected (Treatment on-site)	0.08
	Other	Uncollected (No Treatment)	0.07
	Sewer	Collected (Treatment/No Treatment)	0.67
	None	Uncollected (No Treatment)	0
Urban Low Income	Septic Tank	Uncollected (Treatment on-site)	0.14
	Latrine	Uncollected (Treatment on-site)	0.10
	Other	Uncollected (No Treatment)	0.03
	Sewer	Collected (Treatment/No Treatment)	0.53
	None	Uncollected (No Treatment)	0.20
Rural	Septic Tank	Uncollected (Treatment on-site)	0
	Latrine	Uncollected (Treatment on-site)	0.47
	Other	Uncollected (No Treatment)	0.1
	Sewer	Collected (Treatment/No Treatment)	0.1
	None	Uncollected (No Treatment)	0.33

(Source: Based on 2006 IPCC Guidelines, Vol. 5, Chapter 6, Figure 6.1, Table 6.1 and Table 6.5)

In this assessment, the default degree of utilization rates specified by IPCC for sewer systems serving urban high income and urban low-income group have been further disaggregated using country specific data available on the extent and type of treatment. With regard to rural wastewater, the IPCC default degree of utilization rates specified for rural population in India have not been used. Instead, country-specific data available on connectivity to wastewater systems from Census of India 2001 and 2011 has been used to estimate the corresponding degree of utilization rates for the rural population. The Census of India, however, does not record information for two income groups within the urban population - as is done by the 2006 IPCC Guidelines for National GHG Inventories⁵⁶. Therefore, it is not possible to use the Census of India data to estimate the degree of utilization rates for the urban population and this approach is followed only for the

rural population. The following sections further describe the approach for degree of utilization for urban wastewater and rural wastewater.

Urban Wastewater:

As per India's Second National Communication report¹², about 49.2% of the domestic wastewater generated from the urban centres is not collected. Further, treatment is provided to only 72% of the wastewater that is collected.

While the Second National Communication report further indicates that anaerobic treatment systems are used for about 25% of urban wastewater that is collected and treated; no specific reference documents are indicated in the National Communication report for this information. However, a 2007 Central Pollution Control Board (CPCB) study on "Inventorization of Sewage Treatment Plants"⁶⁸ in which 84 STPs (spread across 9 states and 30 cities) out of a total of 175 STPs in urban areas in the country were assessed, indicates that only 14% of the treatment capacity installed is using anaerobic systems and the remaining 86% of the treatment capacity is using aerobic systems. A similar CPCB study conducted in 2014-15 in which 601 existing STPs were assessed (in class-I and class-II cities spread across 35 states and Union Territories) also indicates that 14% of the wastewater treatment capacity installed is using anaerobic systems and the remaining 86% of the treatment capacity is using aerobic systems. Therefore, it is assumed that for the urban wastewater which is collected only 14% is treated by anaerobic systems and 86% is treated by aerobic systems and this is considered to rework the fractions for degree of utilization given in Table 24.

The estimated fractions for degree of utilization for Urban high and Urban low-income group for sewer systems are indicated in Figure 16, Figure 18 in Annexures, and Table 25.

Assumption: Since year-wise information on the degree of utilization of treatment systems is not available for urban high income and urban low-income groups, constant values have been used for this parameter across the period from 2005-2014.

Figure 16: Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Urban High-Income Group in India

⁶⁸ CPCB (2007): Inventorization of Sewage Treatment Plants in India. Available at http://www.cpcb.nic.in/upload/NewItems/NewItem_99_NewItem_99_5.pdf

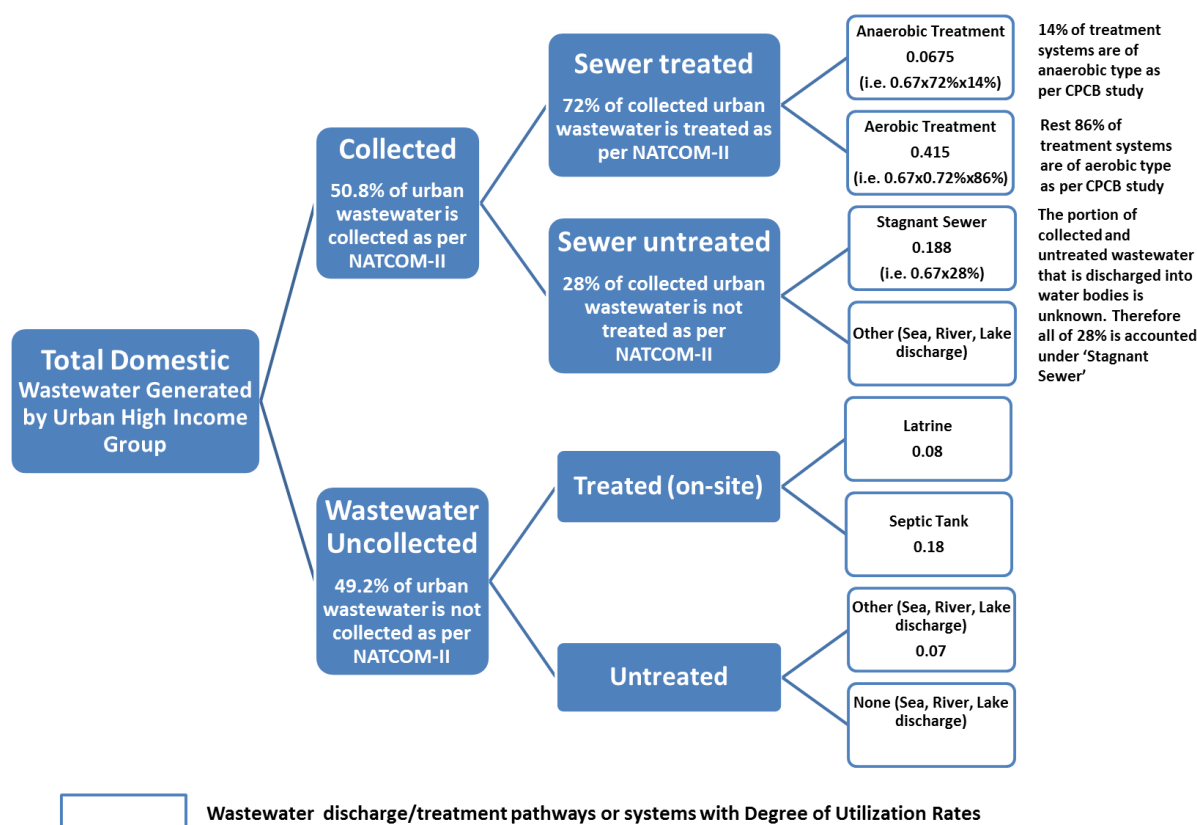


Table 25: Estimated Fractions for Degree of utilization of Sewer based systems for each Urban income group

INCOME GROUP (i) ⁶⁹	TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j)	SPECIFIC TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM TABLE 21 ⁷⁰	DEGREE OF UTILIZATION OF TREATMENT/DISCHARGE PATHWAY OR SYSTEM j, FOR EACH INCOME GROUP FRACTION i (T _{i,j}) ⁷¹	REMARKS
Urban – High (6% of total population – used from 2001 to 2010; 6% of total population – used from 2011 to 2014; refer Table 23)	Septic Tank (uncollected)	Septic Tank (uncollected)	0.18	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines
	Latrine (uncollected)	Latrine (uncollected) (Dry climate, ground water table lower than latrine, small family (3-5 persons))	0.08	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines
	Other (uncollected and not treated)	Sea, river and lake discharge	0.07	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines
	Sewer (collected and not treated)	Stagnant Sewer (collected and not treated)	$0.67 \times 28\% = 0.1876$	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines is 0.67.

⁶⁹ As indicated earlier, in the methane generation calculations, for the period from 2005-2010 the degree of utilization is multiplied with the fraction of Urban high (0.06) and Urban low (0.22) population estimated based on Census report 2001. Similarly, for the period from 2011-2014, the fraction of Urban high (0.06) and Urban low (0.25) population estimated is used based on Census report 2011.

⁷⁰ Based on India's Second National Communication. Available at <http://unfccc.int/resource/docs/natc/indnc2.pdf>

⁷¹ Values for wastewater conveyed through sewer system worked out based on values in Table 2 and 2007 CPCB Report on Evaluation of Operation and Maintenance of Sewage Treatment Plants in India and information given in India's Second National Communication to UNFCCC

INCOME GROUP (i) ⁶⁹	TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j)	SPECIFIC TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM TABLE 21 ⁷⁰	DEGREE OF UTILIZATION OF TREATMENT/DISCHARGE PATHWAY OR SYSTEM j, FOR EACH INCOME GROUP FRACTION i (T _{i,j}) ⁷¹	REMARKS
				28% of collected wastewater is not treated as per Second National Communication.
	Sewer (collected and anaerobic treatment)	Anaerobic Reactor/ Anaerobic digester for sludge (collected and anaerobic treatment)	$0.67 \times 72\% \times 14\% = 0.0675$	Remaining 72% of collected wastewater is treated; of which around 14% is treated anaerobically as per 2007 and 2014-15 CPCB studies on STPs in India ⁷²
	Sewer (collected and other treatment)	Centralized, aerobic treatment plant (not well managed), overloaded (collected and aerobic treatment)	$0.67 \times 72\% \times 86\% = 0.4149$	Remaining 72% of collected wastewater is treated; of which around 86% is treated anaerobically as per 2007 and 2014-15 CPCB studies on STPs in India
	None	Sea, lake and river discharge	0	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines
Urban – low (22% of total population – used from 2001 to 2010; 25% of total population – used from 2011 to 2014; refer Table 23)	Septic Tank (uncollected)	Septic Tank (uncollected)	0.14	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines
	Latrine (uncollected)	Latrine (uncollected) (Dry climate, ground water table lower than latrine, small family (3-5 persons))	0.1	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines
	Other (uncollected and not treated)	Sea, river and lake discharge	0.03	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines
	Sewer (collected and not treated)	Stagnant Sewer (collected and not treated)	$0.53 \times 28\% = 0.148$	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines is 0.53. 28% of collected wastewater is not treated as per Second National Communication.
	Sewer (collected and anaerobic treatment)	Anaerobic Reactor/ Anaerobic digester for sludge (collected and anaerobic treatment)	$0.53 \times 72\% \times 14\% = 0.053$	Remaining 72% of collected wastewater is treated; of which around 14% is treated anaerobically as per 2007 and 2014-15 CPCB studies on STPs in India ⁷³
	Sewer (collected and aerobic treatment) not managed well	Centralized, aerobic treatment plant (not well managed), overloaded (collected and aerobic treatment)	$0.53 \times 72\% \times 86\% = 0.3281$	Remaining 72% of collected wastewater is treated; of which around 86% is treated anaerobically as per 2007 and 2014-15 CPCB studies on STPs in India

⁷² CPCB (2007): Inventorization of Sewage Treatment Plants in India.

Available at http://www.cpcb.nic.in/upload/NewItems/NewItem_99_NewItem_99_5.pdf

CUPS - Inventorization Of Sewage Treatment Plants (2014-15).

Available at http://www.cpcb.nic.in/upload/NewItems/NewItem_210_Inventorization_of_Sewage-Treatment_Plant.pdf

⁷³ CPCB (2007): Inventorization of Sewage Treatment Plants in India.

Available at http://www.cpcb.nic.in/upload/NewItems/NewItem_99_NewItem_99_5.pdf

CUPS - Inventorization Of Sewage Treatment Plants (2014-15).

Available at http://www.cpcb.nic.in/upload/NewItems/NewItem_210_Inventorization_of_Sewage-Treatment_Plant.pdf

INCOME GROUP (i) ⁶⁹	TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j)	SPECIFIC TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM TABLE 21 ⁷⁰	DEGREE OF UTILIZATION OF TREATMENT/DISCHARGE PATHWAY OR SYSTEM j, FOR EACH INCOME GROUP FRACTION i (T _{i,j}) ⁷¹	REMARKS
	None	Sea, lake and river discharge	0.2	Default degree of utilization of the treatment system as per 2006 IPCC Guidelines

Rural Wastewater:

The default values of degree of utilization rates specified for India in the 2006 IPCC Guidelines for National GHG Inventories⁶⁴ indicate that the distribution of septic tanks is '0' for the rural population in India. However, information collated by the Census of India in 2011 on the availability of different types of latrine facilities for wastewater treatment/discharge in households, including septic tanks, indicates that 14.7% of the rural population uses septic tanks (see Table 26). Therefore, country specific data available from the Census of India for 2001 and 2011 is used to calculate the degree of utilization rates of different treatment and discharge systems for the rural population in India.

Information collated by the Census of India in its survey on household amenities and assets⁷⁴ gives insights on how domestic wastewater is handled in rural areas. This includes the portion of wastewater that is collected through the sewer network and portion that is uncollected. The 'piped sewer system' category in the Census survey dataset refers to sewerage network to collect faecal sludge and wastewater as given in Table 26. Thus, it is inferred that 2.2% of rural households were connected to sewer network in 2011 and represent the collected portion of rural domestic wastewater.

Given that wastewater treatment facilities are largely absent in rural areas, the rural wastewater that is collected through the sewer network largely does not undergo any treatment downstream of the sewer network. Therefore, the portion of rural domestic wastewater that is collected and conveyed through the sewer network is assumed to not undergo any treatment and decomposes under aerobic conditions, thereby not leading to CH₄ emission.

The remaining portion of rural domestic wastewater (that is not collected through the sewer network) is either treated on-site through systems such as septic tanks and latrines or discharged without any kind of treatment (see Figure 17). As shown in the Table 26, the Census of India 2001⁷⁴ in its household survey classified 'latrine facilities' into four types namely Water closet, pit latrine, other latrine and no latrine. In the Census of India 2011 survey on household amenities and assets, these 'latrine facilities' are further sub divided into additional categories as follows-

- Water closet is further categorized into Piped sewer system, Septic tank, and Other system
- Other latrine: Night soil disposed into open drain, Service latrine (Night soil removed by human, Night soil serviced by animals)
- Pit latrine: With slab/ventilated improved pit, without slab/open pit
- No latrine within premises

Table 26: Latrine facility types as reported in Census of India

CENSUS OF INDIA – 2001		CENSUS OF INDIA – 2011		REMARKS ON CH ₄ EMISSION GENERATION
CLASSIFICATION OF LATRINE FACILITY	PERCENT OF RURAL HOUSEHOLDS CONNECTED	CLASSIFICATION OF LATRINE FACILITY	PERCENT OF RURAL HOUSEHOLDS CONNECTED	
Water Closet	7.1%	Water Closet	19.4%	Does not generate CH ₄ emission as there is no treatment downstream and decomposes under aerobic condition
		- Piped sewer system	2.2%	

⁷⁴ Census of India, 2011: Houses, Household Amenities and Assets -Latrine facility. Available at http://censusindia.gov.in/2011census/hlo/Data_sheet/India/Latrine.pdf

CENSUS OF INDIA – 2001		CENSUS OF INDIA – 2011		REMARKS ON CH ₄ EMISSION GENERATION
CLASSIFICATION OF LATRINE FACILITY	PERCENT OF RURAL HOUSEHOLDS CONNECTED	CLASSIFICATION OF LATRINE FACILITY	PERCENT OF RURAL HOUSEHOLDS CONNECTED	
		- Septic tank	14.7%	Generates CH ₄ emission
		- Other system	2.5%	Does not generate CH ₄ emissions as Census of India defines these as latrine systems which discharge wastewater to open areas such as streets, yards, drainage ditch, which will therefore lead to wastewater decomposition in aerobic condition
Pit Latrine	10.3%	Pit Latrine	10.5%	
		- With slab/ ventilated improved pit	8.2%	Generates CH ₄ emission
		- Without Slab/ Open pit	2.3%	Generates CH ₄ emission
Other Latrine	4.5%	Other Latrine	0.7%	
		- Night soil disposed into open drain	0.2%	Does not generate CH ₄ emission as the wastewater is disposed into open drain, which will therefore lead to wastewater or septage decomposition under aerobic conditions
		- Night soil removed by humans	0.3%	Does not generate CH ₄ emissions as Census of India indicates that these systems will discharge wastewater/ septage into open areas which will therefore lead to wastewater decomposition in aerobic condition
		- Night soil serviced by animals	0.2%	Does not generate CH ₄ emissions as Census of India indicates that these systems will discharge wastewater/ septage into open areas which will therefore lead to wastewater decomposition in aerobic condition
No latrine within premises	78.1%	No latrine within premises	69.2%	
		- Public latrine	1.9%	Generates CH ₄ emission
		- Open Defecation	67.3%	Does not generate CH ₄ emission as decomposition under aerobic conditions

Note: Discharge or treatment systems which generate CH₄ emission in rural areas indicated in bold in the table

For 2011, the degree of utilization for septic tank and latrine systems (including public, other latrine system) can be estimated directly based on the Census of India 2011 data (see Table 27 and Figure 17). However, the classification of septic tank and latrine systems in the Census of India 2001 is not as detailed as that in Census 2011, thereby presenting challenges in estimating corresponding degree of utilization. For instance, based on the Census 2001 data it is not possible to infer how many of the 7.1% rural households connected to 'Water closet' facility is using septic tanks. In such cases, corresponding proportions of these systems which are available in the Census 2011 data have been used to estimate the percentage distribution of these systems in year 2001. For example, from the Census 2011 data, the percentage contribution of Septic tank in 'Water closet' latrine facility works out to 75.77% i.e. 14.7/ (2.2+14.7+2.5). This proportion has been applied to the total percentage of households connected to 'Water closet' in 2001 to further estimate the percentage of households connected to septic tanks in 2001 as 5.38% i.e. 75.77% of 7.1% (see Table 28). The proportion of 'piped sewer systems' in 2001 under the 'Water closet' category has been estimated similarly. Public latrines in the 'No latrine within premises' category in 2011 (i.e. 2.75%) has been used to estimate the proportion of public latrines in 2001 as 2.14% (i.e. 2.75% of 78.1%). Figure 19 in the Annexure depicts the classification of wastewater discharge/treatment systems and corresponding degree of utilization rates estimated for the rural population in 2001.

Assumption: Since only decadal information on the use of different wastewater treatment/discharge pathways by the rural population is available from the Census of India, the corresponding degree of utilization

estimated for the rural population as per Census of India 2001 and Census of India 2011 data is assumed to be applicable for the two-time periods- 2005-2010 and 2011-2014 respectively across the reporting years in the emission estimates.

Figure 17: Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Rural India, 2011

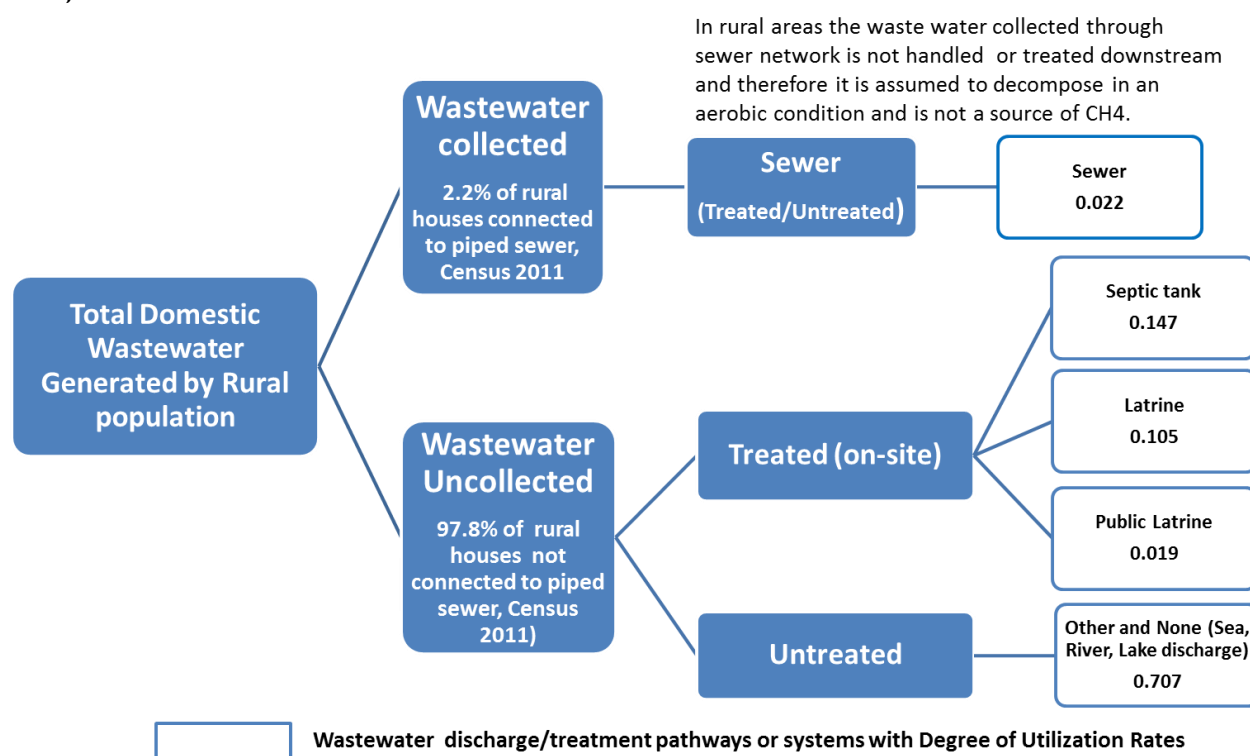


Table 27: Estimated degree of utilization of treatment/ Discharge pathway or system j, for Rural group fraction i (T_{i,j}), 2011 based on Census of India data

CLASSIFICATION OF WASTEWATER TREATMENT/DISCHARGE SYSTEM BASED ON CENSUS DATA ⁷⁴	APPLICABLE TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM TABLE 21 AS PER 2006 IPCC GUIDELINES ¹²	ESTIMATED DEGREE OF UTILIZATION OF TREATMENT/DISCHARGE PATHWAY OR SYSTEM j, FOR RURAL GROUP FRACTION i (T _{i,j}) - 2011	REMARKS
Piped sewer systems	Sewer (Collected and No Treatment)	0.022	2.2% of rural households connected to sewer network as per Census 2011
Septic tank (under Water Closet)	Septic tank (Uncollected and Treatment on-site)	0.147	14.7% of rural households connected to septic tanks as per Census 2011
Pit Latrine	Latrine (Uncollected and Treatment on-site)	0.105	10.5% of rural households connected to pit latrines as per Census 2011
Public Latrine (under No latrine within premises)	Latrine (Uncollected and Treatment on-site)	0.019	1.9% of rural households using public latrines as per Census 2011
Pathway for rest of wastewater that is uncollected and untreated	Others and None (Uncollected and No Treatment)	100%-2.2%-14.7%-10.5%-1.9%= 70.7% i.e. 0.707	The remaining proportion of the rural wastewater is estimated by deducting proportions of the 4 systems listed above in this table. This proportion represents wastewater that is neither collected nor treated. As per 2006 IPCC guidelines, the wastewater discharge/treatment pathways for uncollected and untreated wastewater are

CLASSIFICATION OF WASTEWATER TREATMENT/DISCHARGE SYSTEM BASED ON CENSUS DATA ⁷⁴	APPLICABLE TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM TABLE 21 AS PER 2006 IPCC GUIDELINES ¹²	ESTIMATED DEGREE OF UTILIZATION OF TREATMENT/DISCHARGE PATHWAY OR SYSTEM j, FOR RURAL GROUP FRACTION i (T _{i,j}) - 2011	REMARKS
			categorized as 'Others' and 'None'. The distribution of rural wastewater handled between these two categories cannot be estimated based on available information for India and hence the 'Others' and 'None' categories are clubbed together in the degree of utilization estimation.

Note: Percentage values given in the Census data have been converted into fractions to express the degree of utilization rates

Table 28: Estimated Degree of utilization of treatment/ Discharge pathway or system j, for Rural group fraction i (T_{i,j}), 2001 based on Census of India data

CLASSIFICATION OF WASTEWATER TREATMENT/DISCHARGE SYSTEM BASED ON CENSUS DATA ⁷⁴	APPLICABLE TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM TABLE 21 AS PER 2006 IPCC GUIDELINES ¹²	ESTIMATED DEGREE OF UTILIZATION OF TREATMENT/DISCHARGE PATHWAY OR SYSTEM j, FOR RURAL GROUP FRACTION i (T _{i,j}) - 2001	REMARKS
Piped sewer system	Sewer (Collected and No Treatment)	$11.34\% \times 7.1\% = 0.81\%$ i.e. 0.0081	Piped sewer system accounts for 11.34% of 'Water closet' latrine facility as per Census 2011. This percentage is applied to the percentage of households connected to 'Water closet' (i.e. 7.1%) as per Census 2001 to estimate the corresponding proportion of households connected to septic tanks in 2001.
Septic tank (under Water Closet)	Septic tank (Uncollected and Treatment on-site)	$75.77\% \times 7.1\% = 5.38\%$ i.e. 0.0538	Septic tanks account for 75.77% of 'Water closet' latrine facility as per Census 2011. This percentage is applied to the percentage of households connected to 'Water closet' (i.e. 7.1%) as per Census 2001 to estimate the corresponding proportion of households connected to septic tanks in 2001.
Pit Latrine	Latrine (Uncollected and Treatment on-site)	0.103	10.3% of rural households connected to pit latrines as per Census 2001
Public Latrine (under No latrine within premises)	Latrine (Uncollected and Treatment on-site)	$2.75\% \times 78.1\% = 2.14\%$ i.e. 0.0214	Census 2001 does not include information for public latrines separately. Public latrines account for 2.75% of 'No latrine within premises' category as per Census 2011. This percentage is applied to the percentage of households having 'No latrine within premises' (i.e. 78.1%) as per Census 2001 to estimate the corresponding proportion of households using public latrines in 2001.
Pathway for rest of wastewater that is uncollected and untreated	Others and None (Uncollected and No Treatment)	$100\% - 0.81\% - 5.38\% - 10.3\% - 2.14\% = 81.37\%$ i.e. 0.8137	The remaining proportion of the rural wastewater is estimated by deducting proportions of the 4 systems listed above in this table. This proportion represents wastewater that is neither collected nor treated. As per 2006 IPCC guidelines, the wastewater discharge/treatment pathways for uncollected and untreated wastewater are categorized as 'Others' and 'None'. The distribution of rural wastewater handled

CLASSIFICATION OF WASTEWATER TREATMENT/DISCHARGE SYSTEM BASED ON CENSUS DATA ⁷⁴	APPLICABLE TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM TABLE 21 AS PER 2006 IPCC GUIDELINES ¹²	ESTIMATED DEGREE OF UTILIZATION OF TREATMENT/DISCHARGE PATHWAY OR SYSTEM j, FOR RURAL GROUP FRACTION 1 (T _{1,j}) - 2001	REMARKS
			between these two categories cannot be estimated based on available information for India and hence the 'Others' and 'None' categories are clubbed together in the degree of utilization estimation.

4. Methane Correction Factor (MCFj)

Methane Correction Factor (MCF) is an indication of the degree to which the wastewater treatment system is anaerobic (and thereby generates GHG emission) and this parameter varies with the type of treatment or discharge pathway. The emission factor EF_i for a given type of treatment system or discharge pathway is a product of the maximum CH_4 producing potential (B_0) (default value of 0.6 kg⁷⁵ of CH_4 /kg BOD as per 2006 IPCC Guidelines) and the respective MCF value for type of waste water treatment and discharge system. In the emission estimates, corresponding default MCF values as per the 2006 IPCC Guidelines⁶⁴ (given in Table 21) have been used based on the applicable treatment/discharge pathways or systems for urban and rural population.

Table 29: MCF values considered for various treatment types for Urban High Income, Urban Low Income and Rural Population

TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j)	CLASSIFICATION OF THE SYSTEM (COLLECTED/ UNCOLLECTED AND TREATMENT)	SPECIFIC TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM TABLE 20 ¹²	MCF _j
Urban High Income and Low Income Groups			
Sewer	Collected (Anaerobic treatment)	Anaerobic reactor/Anaerobic digester for sludge	0.80
	Collected (Aerobic treatment)	Centralized, aerobic treatment plant (not well managed, overloaded)	0.30
	Collected (No Treatment)	Stagnant Sewer	0.50
Other	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
None	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
Septic Tank	Uncollected (Treatment on-site)	Septic system	0.50
Latrine	Uncollected (Treatment on-site)	Latrine (Dry climate, ground water table lower than latrine, small family (3-5 members))	0.10
Rural Population			
Sewer	Collected (treated/untreated)	Flowing sewer (Open/Closed)	0
Other	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
None	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
Septic Tank	Uncollected (Treatment on-site)	Septic system	0.50
Latrine	Uncollected (Treatment on-site)	Latrine (Dry climate, ground water table lower than latrine, small family (3-5 members))	0.10
Latrine (Public)	Uncollected (Treatment on-site)	Latrine - Dry climate, ground water table lower than latrine, communal (many users)	0.50

Assumptions:

- The portion of urban wastewater that is collected in sewers but is untreated (28% of urban wastewater) can be handled through 'stagnant sewers' or be discharged into water bodies such as 'sea, lake or river'. The MCF of 'sea, lake or river discharge' is 0.1 and the MCF of 'stagnant sewer' is 0.5. The quantity of this untreated wastewater that is discharged into water bodies is unknown and therefore the entire portion of collected and untreated urban wastewater is accounted under 'stagnant sewer' which has a MCF of 0.5.

⁷⁵ The 2006 IPCC Guidelines define BOD and COD based default values for B_0 . Since the data point for organic content of domestic wastewater is measured in BOD terms, the BOD based default value of 0.6 kg of CH_4 /kg BOD is used in the assessment. As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.2. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

This assumption is based on the largely prevalent condition of untreated wastewater discharged through sewers in urban areas.

- As reported in the Second National Communication¹², the waste water generated in rural areas is not handled or treated in any way and decomposes under aerobic conditions. Using this basis, the proportion of rural wastewater that is collected and conveyed through sewer systems is also assumed to not undergo any treatment downstream and decomposes under aerobic conditions, thereby not leading to CH₄ emissions. Thus, the 'flowing sewer' system having a MCF value of '0' and leading to no GHG emissions is selected as the corresponding treatment system for the proportion of rural wastewater collected through sewer.
- Rural wastewater that is uncollected and untreated can be either discharged into 'sea, lake or river' or 'to ground'. However, the quantity of wastewater that is discharged 'to ground' is unknown and therefore the entire portion of uncollected and untreated rural wastewater is accounted under 'sea, lake or river discharge' which has a MCF of 0.1.

5. Biochemical oxygen demand (BOD)

The primary factor in determining the CH₄ generation potential of wastewater is the amount of degradable organic material in the wastewater. BOD is a common parameter used to measure the organic component of domestic wastewater. Under the same ambient conditions, wastewater with higher BOD concentration will generally yield more CH₄ than wastewater with lower BOD concentration. The BOD concentration indicates only the amount of carbon that is aerobically biodegradable.

2006 IPCC Guidelines for National GHG Inventories provide the default value of BOD generated per person for India is about 34 gm/person/day⁷⁶. However, an average value for BOD of 40.5 gm/person/day is used in the Second National Communication¹² and to maintain consistency, this updated country specific value of 40.5 gm/person/day is used in this analysis as well.

Assumption: Given that updated year-wise values of BOD generated per person are not available, a constant value of 40.5 gm/person/day is used across the reporting period.

6. Correction factor for additional Industrial BOD discharged into sewers (I)

Effluent from industries and establishments is often co-discharged in sewers and mixes with domestic wastewater. As indicated previously the total organics in wastewater (TOW) is directly proportional to BOD value and BOD is the principal factor determining the CH₄ generation potential of domestic wastewater. Wastewater with higher BOD concentrations will generally yield more CH₄ than wastewater with lower BOD concentrations. Both the type of wastewater and the type of bacteria present in the wastewater influence the BOD concentration of the wastewater.

This correction factor, I, accounts for additional BOD from mixing of such industrial and commercial effluent with domestic wastewater. Based on the Second National Communication for India and the 2006 IPCC Guidelines for National GHG Inventories, for Wastewater, the default values of 1.25 for I for collected wastewater and 1 for uncollected wastewater are used in this assessment⁷⁷.

N₂O Emissions from Domestic Wastewater

N₂O emissions can occur as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea.

As per the 2006 IPCC Guidelines and India's Second National Communication, the following equation is used to estimate N₂O emissions from domestic wastewater treatment and discharge⁷⁸

$$N_2O \text{ Emissions} = N_{EFFLUENT} * EF_{EFFLUENT} * 44/28$$

⁷⁶ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.4.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

⁷⁷ Based on 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

⁷⁸ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.7.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Where,

N_2O emissions	= N_2O emissions in inventory year, kg N_2O /yr
$N_{EFFLUENT}$	= nitrogen in the effluent discharged to aquatic environments, kg N/yr
$E_{EFFLUENT}$	= emission factor for N_2O emissions from discharged to wastewater, kg N_2O -N/kg N
44/28	is used for conversion of kg N_2O -N into kg N_2O .

The activity data that is needed for estimating N_2O emissions is nitrogen content in the wastewater effluent, country population and average annual per capita protein consumption (kg/person/yr).

The total nitrogen in the effluent is estimated as follows⁷⁹:

$$N_{EFFLUENT} = (P * Protein * F_{NPR} * F_{NON_CON} * F_{IND_COM}) - N_{SLUDGE}$$

Where

$N_{EFFLUENT}$	= total annual amount of nitrogen in the wastewater effluent, kg N/yr
P	= human population
Protein	= annual per capita protein consumption, kg/person/yr
F_{NPR}	= fraction of nitrogen in protein, kg N/kg protein (default value of 0.16 used as per 2006 IPCC guidelines for wastewater ⁷⁹)
F_{NON_CON}	= factor for non-consumed protein added to the wastewater (default value of 1.1 used as per 2006 IPCC guidelines for wastewater ⁸⁰)
F_{IND_COM}	= factor for industrial and commercial co-discharged protein into the sewer system, (default value of 1.25 used as per 2006 IPCC guidelines for wastewater ⁷⁹)
N_{SLUDGE}	= nitrogen removed with sludge, kg N/yr (default value of 0 used as per 2006 IPCC guidelines for wastewater ⁷⁹)

Data Sources and Assumptions

1. Human Population

The urban and rural population of India is estimated based on population data and decadal population growth trends for the reporting period of 2005-2014 as per the Census of India, 2001 and Census of India, 2011.

2. Annual per capita protein consumption (Protein)

As per NSSO report on Nutritional Intake 2004-05, the protein consumption in urban India is about 57 gm/capita/day. This value is considered in the Second National Communication¹² and in this assessment. Based on NSSO surveys conducted subsequently, the updated per capita protein consumption values for urban population have been used in this assessment as shown in the Table 29. Similarly, corresponding per capita protein consumption values available from the NSSO surveys for rural population have been used in the N_2O emission estimates from rural wastewater. Based on the daily protein consumption, annual protein consumption values have been calculated for urban and rural population and used in the equation to estimate N_2O emissions.

Assumption: Updated year-wise values of per capita protein consumption are not available for urban and population. Therefore, the available values based on NSSO surveys in 2004-05, 2009-10 and 2011-12 are used across the emission reporting period for 2005 to 2008, 2009 to 2010, and 2011 to 2014 respectively as indicated in Table 30.

⁷⁹ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.8.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

⁸⁰ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Section 6.3.1.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Table 30: Values of Daily Per Capita Protein Consumption considered for Urban and Rural Population

YEARS	DAILY PER CAPITA PROTEIN CONSUMPTION-URBAN (GM/CAPITA/DAY)	DAILY PER CAPITA PROTEIN CONSUMPTION-RURAL (GM/CAPITA/DAY)	SOURCE
2005 to 2008	57.0	57.0	Nutritional Intake in India 2004-05, NSSO Report ⁸¹
2009 and 2010	56.15 ⁸²	57.1582	Nutritional Intake in India 2009-10, NSSO Report ⁸³
2011 to 2014	58.0 ⁸⁴	58.684	Nutritional Intake in India 2011-12, NSSO Report ⁸⁵

3.5.3 Uncertainties

Uncertainties in the emission estimates for this source category result from the following factors.

- Distribution of wastewater discharge pathways and treatment systems:** Updated year-on-year data on wastewater generation in urban and rural areas in India and the distribution of different treatment systems is lacking. Given this data constraint, constant values of the IPCC default values for distribution of discharge/treatment systems (i.e. degree of utilization) specified for the urban population have been used across the reporting period. For the rural population, degree of utilization rates has been estimated based on Census 2001 and 2011 data have been applied for the two time periods 2005-2010 and 2011-2013 respectively. Given the lack of updated information, on-ground developments with regard to deployment waste water treatment systems and any ensuing impacts on emissions may not be accurately captured in the estimates.
- MCF based on discharge pathway or treatment system classification:** The MCF represents the degree to which the wastewater treatment system is anaerobic and thereby generates GHG emission. IPCC defined MCF values⁸⁴ depending on the type of discharge pathway or treatment systems are used in the assessment. Due to lack of relevant information, the following assumptions have been made in the emission estimates which contribute to uncertainty.
 - The portion of urban wastewater that is collected in sewers but is untreated (28% of urban wastewater) can be handled through 'stagnant sewers' or be discharged into water bodies such as 'sea, lake or river'. The MCF of 'sea, lake or river discharge' is 0.1 and the MCF of 'stagnant sewer' is 0.5. The quantity of this untreated wastewater that is discharged into water bodies is unknown and therefore the entire portion of collected and untreated urban wastewater is accounted under 'stagnant sewer' which has a MCF of 0.5.
 - Considering the relative lack of infrastructure for wastewater treatment in rural areas, it is assumed that the proportion of rural wastewater that is collected and conveyed through sewer systems does not undergo any treatment downstream and decomposes under aerobic conditions, thereby not leading to CH₄ emissions. Thus, the 'flowing sewer' system having a MCF value of '0' and leading to no GHG emissions is selected as the corresponding treatment system for the proportion of rural wastewater collected through sewer.
 - Rural wastewater that is not collected and untreated can be either discharged into 'sea, lake or river' or 'to ground'. However, the quantity of wastewater that is discharged 'to ground' is unknown and therefore the entire portion of uncollected and untreated rural wastewater is accounted under 'sea, lake or river discharge' which has a MCF of 0.1.
- Operational Performance of Treatment plants:** Furthermore, the performance of existing STPs that handle collected wastewater is observed to unsatisfactory. A number of these plants are not operating to their full capacities and do not conform to the CPCB's environmental standards for discharge of treated wastewater into streams. Hence domestic and industrial wastewater going to the treatment plants is discharged without treatment in some cases. Untreated discharge and mixing of industrial and domestic wastewater will impact the emission generation potential from such wastewater streams. Due to the lack of reliable and regularly reported data on the status of wastewater treatment plants, it is difficult to factor in these considerations in the emission estimates.

⁸¹ Available at http://mospi.nic.in/rept%20%20pubn/513_final.pdf

⁸² 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 2009-10

⁸³ Available at <http://www.indiaenvironmentportal.org.in/files/file/nutrition%20intake%20in%20india.pdf>

⁸⁴ Values based on average of two values across the two schedules in the NSSO survey 2011-12

⁸⁵ Available at http://mospi.nic.in/mospi_new/upload/nss_report_560_19dec14.pdf

- **Population and Urban income group distribution:** Decadal information on the urban and rural population available from the Census of India 2001 and 2011 has been used and population for the intermediate years has been estimated based on observed decadal growth rate. The proportion of urban high income and urban low income population has been estimated based on Census data and IPCC default values for India and applied across the reporting years. These estimates on urban and rural population and distribution of income groups may vary from the actual distribution existing over the reporting period.

As per 2006 IPCC Guidelines, the following conclusions may be drawn regarding uncertainty of GHG emissions from the treatment and disposal of domestic waste water⁸⁶:

Activity data:

- Uncertainty resulting from values considered for Degree of utilization of treatment/discharge pathway or system for each income group (T_{ij}): $\pm 50\%$ for each individual pathway/system
- Uncertainty resulting from values considered for Fraction of population income group (U), particularly for urban high income and low-income group: $\pm 15\%$
- Uncertainty resulting from values of Human population (P): $\pm 5\%$
- Uncertainty related to BOD per person: $\pm 30\%$
- Uncertainty resulting from Correction factor for additional industrial BOD discharged into sewers (I): $\pm 20\%$ for the collected portion of wastewater

Emission factor:

- Uncertainty related to the values of the Fraction treated anaerobically (MCF), depending on the type of technology: Untreated systems and latrines, $\pm 50\%$; Lagoons, poorly managed treatment plants $\pm 30\%$; Centralized well managed plant, digester, reactor, $\pm 10\%$
- Uncertainty related to the Maximum CH_4 producing capacity (B_0): $\pm 30\%$

Sensitivity Analysis for considered MCF values

For cases where information on the exact wastewater treatment or discharge pathway for a part of domestic wastewater is not validated in the National Communication Report¹² or available in other literature, the MCF⁶⁴ values considered in the GHG estimates and possible alternate scenarios are given in the Table 31 below. Three possible alternate scenarios are proposed as follows based on conditions that may exist on the ground (at least partially) and corresponding deviation from the emission estimates has been assessed for each scenario.

- Scenario 1: The estimates consider that the uncollected and untreated portion of Urban and Rural wastewater is discharged to water bodies. The alternate scenario 1 considers that this portion of wastewater is instead discharged to the ground/open land and decomposes under aerobic condition, leading to no GHG emissions.
- Scenario 2: The estimates consider that the portion of urban wastewater collected through the sewer network but not undergoing any treatment downstream is in stagnant condition in the sewers based on the prevalent condition in urban areas. The alternate scenario 2 considers that this portion of wastewater is instead discharged to water bodies without any stagnation taking place in sewer.
- Scenario 3: The 'flowing sewer' type of discharge pathway having no MCF is considered for the portion of rural wastewater collected through the sewer network since this wastewater does not undergo any treatment downstream due to lack of facilities. The alternate scenario 3 considers that this portion of wastewater instead stagnates in the sewer.

Table 31: Alternate Scenarios for MCF values in the Domestic Wastewater Emission Estimates

Table S1: Alternate Scenarios for MCF values in the Domestic Wastewater Emission Estimates				
INCOME GROUP	TREATMENT/ DISCHARGE PATHWAY OR SYSTEM (j)	CORRESPONDING TREATMENT/DISCHARGE PATHWAY OR SYSTEM (j) SELECTED FROM FROM IPCC CLASSIFICATION FOR MCF ⁸⁷		MCF _j
SCENARIO I:				
Consideration in GHG Platform India Final Emission Estimates				
Urban	High	Other (Uncollected and No Treatment)	Sea Lake or river discharge	0.10

⁸⁶ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.7.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

⁸⁷ Based on India's Second National Communication. Available at <http://unfccc.int/resource/docs/natc/indnc2.pdf> and 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

INCOME GROUP	TREATMENT/ DISCHARGE PATHWAY OR SYSTEM (I)	CORRESPONDING TREATMENT/DISCHARGE PATHWAY OR SYSTEM (J) SELECTED FROM FROM IPCC CLASSIFICATION FOR MCF ⁸⁷	MCF _J
Income and Low Income	None (Uncollected and No Treatment)	Sea Lake or river discharge	0.10
Rural	Other (Uncollected and No Treatment)	Sea Lake or river discharge	0.10
	None (Uncollected and No Treatment)	Sea Lake or river discharge	0.10
Consideration in Scenario 1			
Urban High Income and Low Income	Other (Uncollected and No Treatment)	Discharge to ground/open land (aerobic decomposition; no emission)	0
	None (Uncollected and No Treatment)	Discharge to ground/open land (aerobic decomposition; no emission)	0
Rural	Other (Uncollected and No Treatment)	Discharge to ground/open land (aerobic decomposition; no emission)	0
	None (Uncollected and No Treatment)	Discharge to ground/open land (aerobic decomposition; no emission)	0
SCENARIO 2:			
Consideration in GHG Platform India Final Emission Estimates			
Urban High Income and Low Income	Sewer (Collected and No Treatment)	Stagnant Sewer	0.50
Consideration in Scenario 2			
Urban High Income and Low Income	Sewer (Collected and No Treatment)	Sea Lake or river discharge	0.10
SCENARIO 3:			
Consideration in GHG Platform India Final Emission Estimates			
Rural	Sewer (Collected)	Flowing sewer (Open/Closed)	0
Consideration in Scenario 2			
Rural	Sewer (Collected)	Stagnant Sewer	0.50

Table 32: Deviation in Domestic Wastewater GHG emission results based on Sensitivity Analysis

YEAR	GHG PLATFORM INDIA FINAL EMISSION ESTIMATES (MIL. TONNES OF CO ₂ e)	PERCENT DEVIATION W.R.T. CONSIDERED GHG EMISSION ESTIMATES		
		SCENARIO 1	SCENARIO 2	SCENARIO 3
2005	39.04	-21.5%	-5.7%	+1.5%
2006	39.72	-21.5%	-5.7%	+1.5%
2007	40.41	-21.5%	-5.7%	+1.5%
2008	41.11	-21.5%	-5.8%	+1.5%
2009	41.78	-21.6%	-5.8%	+1.5%
2010	42.50	-21.6%	-5.8%	+1.5%
2011	51.47	-21.4%	-5.4%	+3.3%
2012	52.35	-21.5%	-5.4%	+3.3%
2013	53.24	-21.5%	-5.4%	+3.3%
2014	54.15	-21.5%	-5.4%	+3.3%

3.5.4 Source Category specific QA/QC

The internal QC procedures outlined previously in 'GHG estimation preparation, data collection, process and storage' in section 1.3 are carried out for this source category.. Discussions were conducted with experts from CPCB and NEERI over datasets on wastewater generation, wastewater treatment in STPs and rural areas in particular, and for state-wise BOD values. These discussions contributed towards selection of relevant datasets and assumptions to address data gaps in relation to this information.

Specific considerations for the domestic wastewater treatment and discharge category, in view of the emission estimation approach, are indicated below.

The CH₄ and N₂O emissions have been estimated separately for the urban and rural population and therefore, it is checked and confirmed that the corresponding activity data and assumptions relating to the population,

distribution of wastewater discharge/treatment pathways, and per capita protein consumption is appropriately applied for urban and rural areas.

For CH₄ emission estimates relating to urban domestic wastewater, the default degree of utilization rates specified by IPCC for sewer systems serving urban high income and urban low income group have been further broken down using country specific data available on the extent and type of treatment in urban areas. For rural domestic wastewater, the IPCC default values on degree of utilization for rural population indicate that no septic tanks are used in rural areas, whereas the Census of India 2011 data indicates that 14.7% of rural households use septic tanks. Therefore, use of this country-specific information from the Census of India has been preferred over the IPCC default values and the distribution of different wastewater discharge/treatment systems for the rural population have been worked out as reported in previous sections of this document.

The degree of utilization rates which indicate the distribution of wastewater flows through different treatment/discharge pathways, sums up to 100 percent for both urban and rural domestic wastewater respectively, thereby indicating that all collected and uncollected as well as treated and untreated wastewater for urban and rural areas has been accounted for in the emission estimates. Limited availability of published and updated data on the distribution of domestic treatment facilities which can be correlated with the IPCC treatment/discharge pathway classification is a challenge in the source specific QA/QC for this category.

3.5.5 Recalculation

The CH₄ emission estimates for urban domestic wastewater have been recalculated due to changes in the value of fraction of population in Urban high-income group and Urban low income group used in the emission calculation and due to the expansion of the scope to include rural population in the assessment.

Fraction of population in Urban high income and urban low-income group

For the emission estimates in phase I, the default country values for fraction of population in Urban high-income group (0.06) and the fraction of population in Urban low-income group (0.23) as specified by the 2006 IPCC Guidelines⁵⁶ were used for the reporting period from 2007-2012. These fractions for Urban high-income group and Urban low-income group have been updated based on country-specific data from the Census of India 2001 and 2011 for the phase-II estimates. This has resulted in a reduction in the CH₄ emission estimates for the years from 2007 to 2010 and an increase in the CH₄ emission estimates for the years of 2011 and 2012 as indicated in Table 33.

Table 33: Comparison of Fraction of Population in Urban High income and Urban Low-income groups and GHG emission estimation in phase-I and phase-II

YEAR ⁸⁸	FRACTION OF POPULATION IN INCOME GROUP I (U _i) - PHASE-I		FRACTION OF POPULATION IN INCOME GROUP I (U _i) – PHASE-II		CH ₄ EMISSION FOR URBAN DOMESTIC WASTEWATER (MIL. TONNES OF CO ₂ e)		PERCENT DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES
	URBAN HIGH INCOME	URBAN LOW INCOME	URBAN HIGH INCOME	URBAN LOW INCOME	PHASE-I	PHASE- II	
2007	0.06	0.23	0.06	0.22	12.03	11.42	-5.1%
2008	0.06	0.23	0.06	0.22	12.22	11.62	-4.9%
2009	0.06	0.23	0.06	0.22	12.41	11.83	-4.7%
2010	0.06	0.23	0.06	0.22	12.60	12.04	-4.5%
2011	0.06	0.23	0.06	0.25	12.80	13.71	7.1%
2012	0.06	0.23	0.06	0.25	13.02	13.95	7.1%

Inclusion of rural population in the estimation

The scope of assessment has been expanded to include emissions from domestic wastewater treatment and discharge in rural areas. This has resulted in significant increase in the CH₄ emissions from 2007 to 2012 as indicated in the Table 34 given that the considerable proportion of rural population in the country.

⁸⁸ Phase I estimates were limited to the period 2007-2012 and therefore the comparison of phase II estimates in this section is done for the same period.

Table 34: Increase in GHG emission estimates in phase-II as compared to phase-I due to inclusion of rural population in the domestic wastewater estimates

YEAR	CH ₄ EMISSION FOR URBAN DOMESTIC WASTEWATER (MIL. TONNES OF CO ₂ e)		PERCENT DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES
	PHASE-I	PHASE- II	
2007	12.03	24.32	102.3%
2008	12.22	24.76	102.6%
2009	12.41	25.19	103.0%
2010	12.60	25.64	103.4%
2011	12.80	33.86	164.6%
2012	13.02	34.46	164.6%

3.5.6 Verification

An external verification of the emission estimates for this source category has not been undertaken at present. However, relevant QA/QC procedures have been applied internally to ensure reliability of calculations, processing of data, consistency, and transparent and clear documentation of methodology, assumptions and results. The emission estimates have undergone a peer review process and have been finalized subsequently.

The emissions estimated under this assessment for domestic wastewater treatment and discharge have also been compared with the estimates reported for year 2007 and 2010 in India's National communication documents – the Second National Communication¹² and the First Biennial Update Report¹³. It is to be noted that the comparison considers the estimated emissions from urban domestic wastewater treatment and discharge only since the scope of the National communication documents cover urban areas only for this sub-sector. The overall GHG emission estimates from urban domestic wastewater for 2007 and 2010 show an under estimation as compared to the National reporting estimates, with a deviation of 29.3% and 41.5% respectively as compared to Nationally reported emissions. Emissions of CH₄ are underestimated by 36.8% and 24.0% for the year 2007 and 2010 respectively. N₂O emissions are underestimated by 1.3% for the year 2007 and by 62% for the year 2010 as compared to the official estimates reported by India for domestic wastewater treatment and discharge (see Table 35).

Table 35: Comparison of the GHG emission estimates for Urban Domestic Wastewater Treatment and Discharge with Nationally Reported Values

YEAR	EMISSION ESTIMATES FOR URBAN DOMESTIC WASTEWATER TREATMENT AND DISCHARGE	OFFICIAL EMISSION ESTIMATES FOR DOMESTIC WASTEWATER TREATMENT AND DISCHARGE AS PER SECOND NATIONAL COMMUNICATION (2007) AND BIENNIAL UPDATE REPORT (2010)	PERCENT DEVIATION W.R.T. OFFICIAL EMISSION ESTIMATES
CH₄ emissions (Mil. tonnes of CH₄)			
2007	0.543	0.86	-36.8%
2010	0.573	0.75	-24.0%
N₂O emissions (Mil. tonnes of N₂O)			
2007	0.0155	0.0158	-1.3%
2010	0.0165	0.0436	-62.0%
Cumulative GHG emissions (Mil. tonnes of CO₂e)			
2007	16.25	22.98	-29.3%
2010	17.18	29.38	-41.5%

The possible reasons for deviation from the officially reported emissions are discussed below:

- **Proportion of treated and untreated wastewater:** To estimate CH₄ emissions, the extent of wastewater treated aerobically, anaerobically or not treated at all and the type of treatment system used is critical since this impacts the degree of utilization of the wastewater treatment system and the corresponding emission factor – input parameters which subsequently impact the associated GHG emission for each system. Limited clarity and details are provided in the Second National Communication Report¹² and the Biennial Update Report¹³ on the breakup of degree of utilization, assumptions and specific data sources used- specifically for the portion of the domestic wastewater that is collected and conveyed through sewer networks. The variation in the datasets and assumptions used in this assessment

and National Communication has led to deviation in estimates, however given the limited information on activity data and assumptions reported in the National Communication documents, it is difficult to fully understand the underlying reasons.

- **Technology used for treatment:** The Second National Communication report¹² indicates that anaerobic treatment systems are used for about 25% of the domestic wastewater that is collected and treated in India. The official emission estimates are subsequently based on this data which is used to assess the extent of utilization for anaerobic treatment systems to treat wastewater collected through sewer systems. However, no specific reference documents are indicated in the National Communication report for this information. In this assessment, based on the CPCB studies conducted in 2007 and 2014-15 on STPs in India, it is assumed that 14% of wastewater collected through sewer systems in urban areas undergoes anaerobic treatment downstream (see Table 25). The difference in this underlying assumption has contributed to deviation in the two estimates.
- **Population:** The country population used to calculate the CH₄ and N₂O emissions in this assessment has been interpolated for the reporting period based on Census of India 2001 and 2011 data and decadal population growth rates therein. The Second National Communication¹² and the Biennial Update Report¹³ do not provide details of the country population that is used for the estimations. Possible variation in the methods used to arrive at country population can be a likely source of deviation.
- **Variation in protein intake values:** For the estimation of N₂O emissions in year 2007, the protein consumption in urban India is assumed to be 57 gm/capita/day as per the NSSO survey in 2004-05 on nutritional Intake in India 2004-05. The same value is used in the Second National Communication for 2007. For the year 2010, this assessment has used a value of 56.15 gm/capita/day for the protein consumption in urban areas based on the NSSO survey in 2009-10. The Biennial Update Report¹³ does not indicate the value considered for the per capita protein consumption. Deviation in the official estimates of N₂O emissions for 2010 and estimates of this study is higher as compared to 2007. Variation in the values of per capita protein intake and country population is two possible reasons for this. Due to limited information available in the documents, any underlying causes such as assumptions or datasets used in National reporting that contribute to deviation in N₂O emissions are unknown.

3.5.7 Planned improvements

Updated year-on-year data on wastewater generation in urban and rural areas and use of distribution of different treatment systems by households is lacking. In the absence of information, constant values of the IPCC default values for distribution of discharge/treatment systems (i.e. degree of utilization) specified for the urban population have been used across the reporting period. Updated and reliable information is sought on deployment of improved wastewater treatment systems, coverage of sewer networks, proportion of untreated wastewater and its method of disposal in order to accurately capture impacts on emission that programmes or interventions for improved sanitation and wastewater management may have.

Reliable information on sewage treatment plants with regard to volumes treated, underutilization of treatment capacity or any overutilization due to mixing of domestic and industrial wastewater, quality of treatment, and recovery of methane is lacking. Updated information on the same will improve accuracy of the emission estimates.

Updated socio-economic information such as household income levels, actual population distribution by income groups - particularly in line with the IPCC defined income group categorization for urban areas (high-income and low-income) - will help to better capture and report the disaggregated emissions for these income-categories and subsequently inform targeted interventions.

Going forward, the GHG Platform India could look at including activities to collect primary data on wastewater generation, its characteristics and treatment, to some extent, to improve reliability of the estimates. The Platform could help promote and provide technical inputs towards recording and reporting of relevant activity data in an accurate, consistent and transparent manner. The Platform could also engage further with the Ministry of Environment, Forests and Climate Change to gain access to the underlying datasets and assumptions used for the official National GHG emission estimates. This will greatly help in improving the accuracy of this assessment, enable better comparability, and help identify and address any limitations in the domestic wastewater estimates prepared under this assessment as well as official emission estimates

3.6 4D2 Industrial Wastewater Treatment and Discharge

3.6.1 Category Description

CH₄ is emitted from industrial waste water when it is treated or disposed anaerobically. Waste water from industrial sources may be treated on site, transferred through a sewer to a centralized treatment plant or disposed of untreated in nearby areas or via an outfall.

The Scope of the national GHG emissions assessment is limited to only those industrial sectors with substantial generation of wastewater containing organic matter, thereby leading to release of GHG emissions from treatment and/or discharge of such organic wastewater. In line with India's National Communications, related documentation from NEERI⁸⁹ and the 2006 IPCC guidelines for National GHG inventories⁵⁶, 12 industry sectors have been included for estimating CH₄ from industrial waste water. The product categories for the 12 industry sectors are indicated in Table 36.

Table 36: Industrial Sectors and products considered

Iron and Steel	Production of Pig Iron, Sponge Iron and Finished steel (alloy & Non-alloy)
Fertilizer	Production of Nitrogenous and Phosphatic Fertilizers (finished product for sale)
Beer	Production of all types of Beer (alcoholic)
Meat	Finished Meat production from all the registered Slaughterhouses
Sugar	Finished Sugar production from cane
Coffee	Production of all types of coffee (Arabica, Robusta and varieties of these) in India
Soft Drink	Production of non-alcoholic soft drinks
Pulp & Paper	Production of paper ⁹⁰ from all pulp and paper industries in India
Petroleum	Refining and production of Petroleum, Oil and Lubricants ⁹¹
Rubber	Production of Finished Natural and Synthetic Rubber
Dairy	Production of milk in the Dairy Sector in India
Tannery	Production of Raw Bovine, Sheep, lamb, Goat and kid skins and hides

The other industrial sectors which consume and discharge chemicals or other inorganic matter which are not sources of significant GHG emission, such as Cement industry, Plastic industry, Pharmaceuticals, Automobile industry etc., are not included in the analysis. This assessment is applicable for all on-site generation and treatment of industrial wastewater for the industrial sectors listed above within India. Assessment of CH₄ production potential from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater generated, and the type of prevalent wastewater treatment systems used by the respective industrial sector.

Due to lack of documented information on the total volume of wastewater generated from industrial sectors, a tier I approach which uses industrial production as a metric to estimate volume of wastewater generation is used. Secondary data on industrial production between the years 2005 – 2013 is sourced from multiple entities such as the Ministry of Steel, Indian Bureau of Mines, National Federation of Cooperative Sugar Factories Limited, the Coffee Board, the Fertilizer Association of India, the Annual Survey of Industries (ASI), Ministry of Statistics and Programme Implementation (MOSPI), and the Rubber Board, Food & Agriculture organization, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture, to name a few. Where the use of country-specific information is not feasible due to limitations in the data, IPCC defined default values have been used.

⁸⁹ Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, NEERI, 2010. Available at: <http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf>; Impact of methane emissions from wastewater sector in India through a case study of an effluent treatment plant, NEERI, 2011. Available at: <http://www.cseindia.org/userfiles/Karthik.pdf>

⁹⁰ Paper produced from various raw materials – Wood, Agro and Recycled fiber based raw materials which is used for various purposes – writing, printing, newsprint and packaging are all included

⁹¹ Industrial output/production data is considered from petroleum refining and not from crude oil extraction since water consumption and wastewater generation is significant in the refining process. International Petroleum Industry Environmental Conservation Association (IPIECA) (2010): Petroleum refining water/wastewater use and management- Operations Best Practice series

Table 37: Principal Sources and Quality of Data for Industrial Wastewater Treatment and Discharge Estimates

IPCC ID	GHG SOURCE & SINK CATEGORIES	TYPE	QUALITY	SOURCE
4DI	Domestic wastewater treatment and discharge	Secondary	Medium	• NEERI • Ministry of Steel • Indian Bureau of Mines • The Fertilizer Association of India • Annual Survey of Industries, Ministry of Statistics and Programme Implementation • National Federation of Cooperative Sugar Factories Limited • Coffee Board, Ministry of Commerce and Industry • Petroleum Planning and Analysis Cell, Ministry of Petroleum & Natural Gas • Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture • Office of the Principal Scientific Adviser to the Government of India • Network for Certification and Conservation of Forests • Rubber Board, Ministry of Commerce and Industry • Food and Agriculture Organization (FAO) • Centre for Science and Environment (CSE) • 2006 IPCC Guidelines on national GHG inventories

Country specific wastewater generation rates are used for all 12 sectors based on NATCOM, NEERI and CSE data. Degradable organic concentration in the wastewater (kg COD/m^3) for 8 sectors is based on NATCOM & NEERI data and for 4 sectors is based on IPCC default data. Maximum CH_4 producing capacity, $\text{kg CH}_4/\text{kg COD (B}_o\text{)}$ and MCF values are also based on IPCC default data. Due to lack of country-specific data on the emission factors for CH_4 emissions from industrial wastewater, default values of these emission factors as specified by the 2006 IPCC Guidelines for National GHG Inventories⁵⁶ have been used in this assessment.

Industrial production data reported in potential single source datasets such as the ASI and industry associations is found to be in disparate units. The requisite guidance for normalization/conversion of the production data to a single unit (i.e. tonnes as required in the emission calculation) is absent and this has necessitated the use of multiple data sources for each of the industrial sectors under consideration. While data has been sourced from alternate published data sources, these data sources themselves collate data from several sources which has impacted quality and reliability of the data. Due to the lack of updated year-on-year information on the changes in volume of wastewater generated per tonne of product - a parameter that should vary given the improvements in production technologies - constant values have been used for this parameter across the reporting period for all industry sectors, except for the Pulp and Paper sector where such information was available for a few years. Therefore, the activity data used in the emission estimates for industrial wastewater is assessed to be of medium quality overall.

Activity data is largely sourced from official publications from government departments and nodal institutions/associations (see section 3.6.2 on Methodology for further details on assumptions and emission factors used)⁹². An assessment of the quality of activity data and emission factors used in the estimation is indicated in the Table 38 below. The quality has been assessed based on the source of the data⁹³ and its availability. Published data sourced from government institutions and agencies is deemed to be of 'high' quality for the years where such published data is available. Data from peer reviewed literature and studies undertaken by research and academic institutions with experience of working in the waste sector is deemed to be of 'medium' quality. Data sourced from private organizations, online databases, and individual researchers is deemed to be of 'low' quality. Further, for years wherein no data has been published for the parameter, the quality is assigned as 'low', with suitable assumptions used to address data gaps in such cases. Emission factors and default values sourced from the 2006 IPCC Guidelines⁵⁶ have been assessed to be of 'high' quality.

⁹² It is difficult to assess the quality of activity data by state since industrial activity for a particular sector is non-existent in some states. Therefore, a qualitative assessment has been done for each industry sector, since this is largely applicable across all states for a particular sector.

⁹³ Data sources for all parameters for industrial wastewater are indicated further in section 3.6.2 of this note.

- Data and trends from Annual Reports, status papers, statistical records of numerous ministries and departments such as Ministry of Agriculture, Ministry of Steel, Ministry of Commerce & Industry, Ministry of Petroleum & Natural Gas, Rubber Board have been used for data on 'Industrial production (Pi)' for the industry sectors considered in estimates. Therefore, the quality of data is considered as 'high' for the years wherein published national-level industrial production datasets from such institutions are available while 'low' quality is assigned for years wherein reliable data is not available. Issues were found with quality and availability of industrial production data for the Fertilizers, Sugar, Beer and Soft Drink sectors, thereby requiring use of information from private sources and apportionment based on annual rate of growth for Soft Drink and Beer sectors in the emission estimation and therefore 'low' quality has been assigned across the estimation period for these sectors.
- Information on 'volume of wastewater generated per tonne of product' has been sourced from published data from NEERI and India's Second National Communication for year 2007 for 9 sectors and is deemed to be of 'high' quality for this year. For the Pulp and Paper sector, this information is based on a study undertaken by CSE which provides values for years 2011 and 2012 and is therefore gauged to be of 'medium' quality for these two years.
- The values for 'Degradable organic component in industrial wastewater (COD_i)' used for Sugar, Dairy, Tannery and Pulp & Paper sectors are sourced from NEERI's published document on India's National Communication for year 2007 and are thus assessed to be of 'high' quality for this year. The COD values for Iron & Steel, Fertilizers and Rubber sectors is based on a NEERI study but pertain to year 2003 which falls outside the emission estimation period and therefore quality is assessed to be 'low' for these sectors. The COD values for Coffee, Petroleum and Meat sectors is sourced from the 2006 IPCC Guidelines for national GHG inventories and are thereby gauged to be of 'high' quality.
- 'Methane correction factor (MCF_i)' value is based on the prevalent wastewater treatment system used in the respective industrial sector (see Table 44 in section 3.6.2). While the MCF values for corresponding treatment technologies has been sourced from the 2006 IPCC Guidelines for National GHG Inventories, information on prevalent treatment system used is based on Second National Communication documents, 2006 IPCC Guidelines for National GHG Inventories, and sector specific publications and the quality is assessed accordingly. MCF for Coffee and Meat are based on the 2006 IPCC Guidelines for National GHG Inventories and thus assessed to be of 'high' quality. Information for this parameter for Fertilizer, Dairy, Sugar, Pulp & Paper, Tannery is sourced from India's Second National Communication and is thus assessed to be of 'high' quality for year 2007. MCF for Iron & Steel and Petroleum is based on private organization and independent research based publications and is thus assessed to be of 'low' quality. Information sourced for the Tannery sector pre-dates the estimation period 2005-2014 and is therefore assessed to be of 'low' quality.
- Values for the following parameters and emission factors for all industry sectors are sourced from the 2006 IPCC Guidelines for National GHG Inventories⁵⁶. Therefore, the quality is assessed to be 'high' across the emission estimation period.
 - Organic component removed as sludge (Si)
 - Amount of CH₄ recovered (Ri)
 - Maximum CH₄ producing capacity (Bo)

Table 38: Qualitative Assessment of Year-wise Activity and Emission Factor Data used in the Industrial Wastewater Treatment and Discharge Estimates

S. No.	ACTIVITY DATA/EMISSION FACTOR	QUALITY									
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
I	Activity Data										
(a)	Industrial Production (Pi)										
	Iron & Steel	H	H	H	H	H	H	H	H	H	H
	Fertilizers	L	L	L	L	L	L	L	L	L	L
	Sugar	L	L	L	L	L	L	L	L	L	L
	Coffee	H	H	H	H	H	H	H	H	H	H
	Petroleum	H	H	H	H	H	H	H	H	H	H
	Dairy	H	H	H	H	H	H	H	H	H	H
	Meat	H	H	H	H	H	H	H	H	H	H
	Beer	L	L	L	L	L	L	L	L	L	L
	Soft Drink	L	L	L	L	L	L	L	L	L	L
	Pulp & Paper	H	H	H	H	H	H	H	H	L	L

S. No.	ACTIVITY DATA/EMISSION FACTOR	QUALITY									
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	Rubber	H	H	H	H	H	H	H	H	H	H
	Tannery	H	H	H	H	H	H	H	H	H	H
(b)	Wastewater generated, m ³ /t product (Wi)										
	Iron & Steel	L	L	H	L	L	L	L	L	L	L
	Fertilizers	L	L	H	L	L	L	L	L	L	L
	Sugar	L	L	H	L	L	L	L	L	L	L
	Coffee	L	L	H	L	L	L	L	L	L	L
	Petroleum	L	L	H	L	L	L	L	L	L	L
	Dairy	L	L	H	L	L	L	L	L	L	L
	Meat	L	L	H	L	L	L	L	L	L	L
	Beer	L	L	H	L	L	L	L	L	L	L
	Soft Drink	L	L	H	L	L	L	L	L	L	L
	Pulp & Paper	L	L	L	L	L	L	M	M	L	L
	Rubber	L	L	H	L	L	L	L	L	L	L
	Tannery	L	L	H	L	L	L	L	L	L	L
(c)	Chemical oxygen demand (CODi)										
	Iron & Steel	L	L	L	L	L	L	L	L	L	L
	Fertilizers	L	L	L	L	L	L	L	L	L	L
	Sugar	L	L	H	L	L	L	L	L	L	L
	Coffee	H	H	H	H	H	H	H	H	H	H
	Petroleum	H	H	H	H	H	H	H	H	H	H
	Dairy	L	L	H	L	L	L	L	L	L	L
	Meat	H	H	H	H	H	H	H	H	H	H
	Beer	H	H	H	H	H	H	H	H	H	H
	Soft Drink	L	L	L	L	L	L	L	L	L	L
	Pulp & Paper	L	L	H	L	L	L	L	L	L	L
	Rubber	L	L	L	L	L	L	L	L	L	L
	Tannery	L	L	H	L	L	L	L	L	L	L
(d)	Organic component removed as sludge (Si)	H	H	H	H	H	H	H	H	H	H
(e)	Amount of CH ₄ recovered (Ri)	H	H	H	H	H	H	H	H	H	H
2	Emission Factors										
(a)	Methane correction factor (MCFi)										
	Iron & Steel	L	L	L	L	L	L	L	L	L	L
	Fertilizers	H	H	H	H	H	H	H	H	H	H
	Sugar	H	H	H	H	H	H	H	H	H	H
	Coffee	H	H	H	H	H	H	H	H	H	H
	Petroleum	L	L	L	L	L	L	L	L	L	L
	Dairy	H	H	H	H	H	H	H	H	H	H
	Meat	H	H	H	H	H	H	H	H	H	H
	Beer	H	H	H	H	H	H	H	H	H	H
	Soft Drink	H	H	H	H	H	H	H	H	H	H
	Pulp & Paper	H	H	H	H	H	H	H	H	H	H
	Rubber	H	H	H	H	H	H	H	H	H	H
	Tannery	H	H	H	H	H	H	H	H	H	H
(b)	Maximum CH ₄ producing capacity(Bo)	H	H	H	H	H	H	H	H	H	H

Notes: H- high, M-medium, L-low

3.6.2 Methodology

A Tier I approach has been followed to estimate the CH₄ emissions from industrial wastewater since country-specific data on volumes of industrial wastewater generated is not available. 12 industrial sectors with substantial organic wastewater generation are considered in the emission estimation. Emission estimation for each sector based on the following parameters:

- Industrial production in tonnes

- Wastewater generated per tonne of product
- Organic concentration (i.e. characteristic of wastewater)
- MCF based on broad treatment technology used by sector
- Methane recovery (if any)

A top-down approach has been followed and country-specific activity data has been sourced for most of the industry sectors, with IPCC default values used where such data is unavailable. Default values of the emission factors as per the 2006 IPCC Guidelines for National GHG Inventories⁵⁶ have been used in the calculations. In some industries, CH₄ is recovered from industrial wastewater, and in the present calculations, CH₄ recovered for energy purposes in sugar, beer and dairy industries has been subtracted from the total CH₄ estimated to be emitted from these industries (recovery rate was 70%, 75% and 75% respectively¹²).

Table 39: Type of Emission Factor and Level of Methodological Tier adopted for Industrial Wastewater Treatment and Discharge Estimates

IPCC ID	GHG SOURCE & SINK CATEGORIES	CH ₄	
		METHOD APPLIED	EMISSION FACTOR
4DI	Industrial wastewater treatment and discharge	TI	D

Notes: TI: Tier I; D: IPCC default

As per the 2006 IPCC Guidelines and India's National Communication, the following equation is used to estimate CH₄ emissions from industrial wastewater treatment⁹⁴.

$$CH_4 \text{ Emissions} = \sum_i [(TOW_i - S_i) EF_i - R_i]$$

Where:

- CH₄ Emissions = CH₄ emissions in inventory year, kg CH₄/yr
- TOW_i = total organically degradable material in wastewater from industry i in inventory year, kg COD/yr
- i = industrial sector
- S_i = organic component removed as sludge in inventory year, kg COD/yr (Default value 0.35 as per 2006 IPCC Guidelines for National GHG Inventories⁵⁶ and India's Second National Communication report¹²)
- EF_i = emission factor for industry i, kg CH₄/kg COD for treatment/discharge pathway or system(s) used in inventory year
- R_i = amount of CH₄ recovered in inventory year, kg CH₄/yr

The activity data for this source category is the amount of organically degradable material in the wastewater (TOW), which is a function of industrial output (product) P (tonnes/year), wastewater generation W (m³/ton of product), and degradable organics concentration in the wastewater COD (kg COD/m³) as given in the equation⁹⁵:

$$TOW_i = P_i \cdot W_i \cdot COD_i$$

Where:

- TOW_i = total organically degradable material in wastewater for industry i, kg COD/yr
- i = industrial sector
- P_i = total industrial product for industrial sector i, t/yr
- W_i = wastewater generated, m³/t product
- COD_i = chemical oxygen demand (industrial degradable organic component in wastewater), kg COD/m³

For each industrial sector, the emission factor is estimated using the maximum methane producing capacity and the average methane correction factor (MCF) based on the type of treatment method used by the

⁹⁴ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.4. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

⁹⁵ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.5. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

industry. The MCF indicates the extent to which the CH₄ producing potential (B₀) is released in each type of treatment method and thereby it is an indication of the degree to which the system is anaerobic.

$$CH_4 \text{ EMISSION FACTOR } EF_j = B_0 \cdot MCF_j$$

Where:

- EF_j = emission factor for each treatment/discharge pathway or system used by the industry, kg CH₄/kg COD
 j = each treatment/discharge pathway or system
 B₀ = maximum CH₄ producing capacity, kg CH₄/kg COD (Default value 0.25%)
 MCF_j = methane correction factor (fraction)

Table 40: Default MCF values based on treatment type and discharge pathway or system for Industrial Wastewater

TYPE OF TREATMENT AND DISCHARGE PATHWAY OR SYSTEM	DETAILS	MCF
Untreated		
Sea, river and lake discharge	Rivers with high organics loadings may turn anaerobic, however this is not considered here	0.1
Treated		
Aerobic treatment plant	Well managed	0
Aerobic treatment plant	Not well managed. Overloaded	0.3
Anaerobic digester for sludge	CH ₄ recovery not considered	0.8
Anaerobic reactor (e.g., UASB, Fixed Film Reactor)	CH ₄ recovery not considered	0.8
Anaerobic shallow lagoon	Depth less than 2 metres	0.2
Anaerobic deep lagoon	Depth more than 2 metres	0.8

(Source: 2006 IPCC Guidelines, Vol. 5, Chapter 6, Table 6.8)

Data Sources and Assumptions

I. Industrial Production (P_i)

The volume of wastewater generated, degradable organic matter and the Methane Correction factor are key parameters required to calculate GHG emissions from industrial wastewater as indicated in the equations in the previous section. Industrial production is a crucial starting point in the activity dataset to estimate the total wastewater generation for each industrial sector using the output based method (i.e. based on m³ of wastewater generated per tonne of industrial product for each sector).

The following sources have been used to obtain the Industrial production data for the industrial sectors under consideration.

Table 41: Data sources for Industrial Production data

SECTOR	PERIOD	DATA SOURCE
Iron & Steel	2004-05; 2005-06 & 2006-07	Ministry of Steel - Annual Report 2007-08, Annexure III ⁹⁷
	2007-08 to 2009-10	Indian Bureau of Mines- The Indian Minerals Yearbook 2012 (Part- II: Metals & Alloys – Iron & Steel and Scrap) ⁹⁸
	2010-11 to 2013-14	Indian Bureau of Mines- The Indian Minerals Yearbook 2015 (Part- II: Metals & Alloys – Iron & Steel and Scrap) ⁹⁹
Fertilizer	2004-05 to 2013-14	The Fertilizer Association of India – Statistical Database- All India Production of Fertilizers ¹⁰⁰
Beer	2004-05 to 2011-12	Data as per Central Statistical Organisation; compiled by Indiatat ¹⁰¹ . Production data for 2012-13 and 2013-14 is not

⁹⁶ As per 2006 IPCC Guidelines, Vol.5, Chapter 6: Wastewater Treatment and Discharge, Section 6.2.3.2 and NEERI document on Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, 2010. Available at: <http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf>

⁹⁷ Available at <http://steel.gov.in/sites/default/files/Annual%20Report%20%282007-08%29.pdf>

⁹⁸ Available at <http://ibm.nic.in/writereaddata/files/07092014130558IMYB-2012-Iron%20%26%20Steel%20and%20Scrap.pdf>

⁹⁹ Available at <http://ibm.gov.in/index.php?c=pages&m=index&id=550>

¹⁰⁰ Available at <http://www.faidelhi.org/general/Production%20of%20Fertilisers.pdf>

¹⁰¹ The year-on-year production data for Beer sector reported in the ASI dataset shows high variance for the emission estimation period. Moreover, industrial production data collated by the ASI is available in multiple units of measurement and

SECTOR	PERIOD	DATA SOURCE
		available and has been estimated based on average CAGR of 19.89% in the reported data from 2004-05 to 2011-12.
Sugar	2004-05 to 2013-14	National Federation of Cooperative Sugar Factories Limited, Cooperative Sugar, November, 2014, p.26
Coffee	2004-05 to 2013-14	Market Research & Intelligence Unit, Coffee Board, Ministry of Commerce and Industry – Database on Coffee, June/July 2016 ¹⁰²
Soft Drink	2004-05 to 2010-11	Data as per Central Statistical Organisation; compiled by Indiatat ¹⁰³ . Production data for 2011-12, 2012-13 and 2013-14 is not available and has been estimated based on average volume growth of 5% CAGR in reported for the soft drink industry in India ¹⁰⁴ .
Petroleum	2004-05 to 2013-14	Petroleum Planning and Analysis Cell, Ministry of Petroleum & Natural Gas – Production of Petroleum Products ¹⁰⁵
Dairy	2004-05 to 2013-14	Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture - Basic Animal Husbandry & Fisheries Statistics, 2015, Table 1 ¹⁰⁶
Meat	2004-05 to 2013-14	Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture - Basic Animal Husbandry & Fisheries Statistics, 2015, Table 18 ¹⁰⁷
Pulp and Paper	2005-06 to 2011-12	Office of the Principal Scientific Adviser to the Government of India - Opportunities for Green Chemistry Initiatives: Pulp and Paper, Table 2.4 ¹⁰⁸
	2012-13 & 2013-14	Network for Certification and Conservation of Forests (NCCF) (2017): Draft Policy Paper on Promoting Sustainable Trade of Wood and Wood Based Products in India, Table 6 ¹⁰⁹
Rubber	2004-05 & 2005-06	Statistics & Planning Department, Rubber Board- Rubber Statistical monthly News -June 2006 ¹¹⁰
	2006-07 & 2007-08	Statistics & Planning Department, Rubber Board – Indian Rubber Statistics ¹¹¹
	2008-09 to 2010-11	Statistics & Planning Department, Rubber Board- Rubber Statistical monthly News –July 2011 ¹¹²
	2011-12 & 2012-13	Statistics & Planning Department, Rubber Board- Rubber Statistical monthly News –May 2013 ¹¹³
	2013-14	Statistics & Planning Department, Rubber Board- Rubber Statistical monthly News –September 2014 ¹¹⁴
Tannery	2005-2015 (data available on calendar year basis)	Food and Agriculture Organization (FAO)- World Statistical Compendium for raw hides and skins, leather and leather footwear 1998-2015, Table 5, Table 7 and Table 9 ¹¹⁵

cannot be aggregated into a single unit of 'tonnes' of industrial product which is required for calculating emissions. Therefore, the ASI dataset has not been used to source activity data for Beer. Given that the required activity data is not available in other open source resources in the public domain, this dataset on beer production has been referred from the [Indiatat database](#).

¹⁰² Refer to Table 1.4 of document available at http://www.indiacoffee.org/Database/DATABASE_July16_1.pdf

¹⁰³ The year-on-year production data for Soft Drink sector reported in the ASI dataset shows high variance for the emission estimation period. Moreover, industrial production data collated by the ASI is available in multiple units of measurement and cannot be aggregated into a single unit of 'tonnes' of industrial product which is required for calculating emissions. Therefore, the ASI dataset has not been used to source activity data for Soft Drink sector. Given that the required activity data is not available in other open source resources in the public domain, this dataset on soft drink production has been purchased from the [Indiatat database](#).

¹⁰⁴ Available at <http://www.nielsen.com/content/dam/corporate/in/docs/reports/2016/nielsen-featured-Insights-what's-bubbling-up-in-india's-soft-drink-market.pdf>

¹⁰⁵ Available at http://www.ppac.org.in/content/146_1_ProductionPetroleum.aspx. Refer 'Historical By Product' spreadsheet under 'Production of Petroleum Products' category

¹⁰⁶ Available at http://dahd.nic.in/sites/default/files/BAH_%26_FS_Book.pdf

¹⁰⁷ Available at http://dahd.nic.in/sites/default/files/BAH_%26_FS_Book.pdf

¹⁰⁸ Available at http://psa.gov.in/sites/default/files/Pulp_Paper_Final.pdf

¹⁰⁹ Available at http://nccf.in/wp-content/uploads/2017/03/Draft-Policy-Paper-on-Wood-based-industries_NCCF_feb-2017.pdf

¹¹⁰ Available at http://www.rubberboard.org.in/RSN/RSN_June06.pdf

¹¹¹ Available at http://rubberboard.org.in/IRS_Vol33.pdf

¹¹² Available at http://www.rubberboard.org.in/RSN/RSN_July2011.pdf

¹¹³ Available at [http://www.rubberboard.org.in/RSN/RSN_News_May2013\(annual\).pdf](http://www.rubberboard.org.in/RSN/RSN_News_May2013(annual).pdf)

¹¹⁴ Available at <http://www.rubberboard.org.in/RSN/rsnewssep2014.pdf>

¹¹⁵ Available at <http://www.fao.org/3/a-i5599e.pdf>

Assumptions:

- To ensure consistency with India's Second National Communication Report¹² and the Biennial Update Report¹³, the GHG emission inventory is to be prepared on a calendar year basis. For all the industrial sectors included in this assessment except Tannery sector, production data is available on a financial year basis has been apportioned on a calendar year basis. Production datasets available on financial year basis have been converted to calendar year datasets for a given calendar year by considering 3/4th of the value from the previous financial year (corresponding to 9 months from April to December out of 12 months in a year) and 1/4th from the next financial year (corresponding to 3 months from January to March out of 12 months in a year). For example, 3/4th of the production data from the financial year 2004-05 and 1/4th of the production data from the financial year 2005-06 has been considered and added together to estimate the production data for the calendar year 2005, and so on. Production data for Tannery sector was already reported for the calendar year and thus no further estimation was required to convert this data to calendar year basis.
- Production data for the Pulp and Paper sector was not available for financial year 2004-05. In this case, the value of the production data available for financial year 2005-06 is considered as the production data for calendar year 2005.
- Production data for the Soft drink sector was not available for the years for 2011-12, 2012-13 and 2013-14. This missing activity data has been estimated based on average volume growth of 5% CAGR in reported for the soft drink industry in India¹¹⁶. The activity data on soft drink production is reported in terms of number of bottles. This has been initially converted to volume basis by assuming each standard size of each bottle as 500 ml based on inputs from the Indian Beverage Association and subsequently to mass basis (unit of tonnes as required in the emission calculation equation) by using the average density of 1.04 gm/ml for soft drinks. Soft drink production data for 2010-11 is available only for 9 months and has been extrapolated to annual basis by scaling it up by 1.25 times.
- Production data for the Beer sector was not available for years 2012-13 and 2013-14. This missing activity data has been estimated based on average CAGR of 19.89% observed in the available activity data from 2004-05 to 2011-12. The activity data on beer production reported in kiloliter has been converted to the mass basis (unit of tonnes as required in the emission calculation equation) by using the average density of 1.0 gm/ml for beer. Beer production data for 2011-12 is available only for 9 months and has been extrapolated to annual basis by scaling it up by 1.25 times.

2. Wastewater generated per tonne of product (W_i)

A combination of country specific and default values has been used for this coefficient. The following data sources are used, in the order of preference to prioritize the use of country specific values for this coefficient (based on the availability of information)

- India's Second National Communication to the UNFCCC
- related NEERI¹¹⁷ documentation (indicated in the following Table)
- 2006 IPCC Guidelines (Vol. 5, Chapter 6: Wastewater Treatment and Discharge)

The values for wastewater generation per tonne of production and respective data sources are indicated in the Table 42 below.

Table 42: Industry-wise Wastewater generation per tonne of Product

INDUSTRY	WASTEWATER GENERATION (M ³ /TONNE OF PRODUCT)	REFERENCE
Iron & Steel	60	India's Second National Communication to the UNFCCC, 2012, Box 2.7 ¹¹⁸
Fertilizer	8	India's Second National Communication to the UNFCCC, 2012, Box 2.7
Beer	9	India's Second National Communication to the UNFCCC, 2012, Box 2.7
Sugar	1	India's Second National Communication to the UNFCCC, 2012, Box 2.7

¹¹⁶ Available at <http://www.nielsen.com/content/dam/corporate/in/docs/reports/2016/nielsen-featured-Insights-what's-bubbling-up-in-india's-soft-drink-market.pdf>

¹¹⁷ NEERI was the lead institution involved in the estimation of GHG emissions from industrial wastewater for the Waste sector. NEERI has been contacted for details on the methodology and information for this assessment and in case of data gaps or limited availability of information in the National Communication reports, preference has been given to relevant NEERI documents.

¹¹⁸ Available at <http://unfccc.int/resource/docs/natc/indnc2.pdf>

INDUSTRY	WASTEWATER GENERATION (M ³ /TONNE OF PRODUCT)	REFERENCE
Coffee	5	India's Second National Communication to the UNFCCC, 2012, Box 2.7
Soft Drink	3.7	India's Second National Communication to the UNFCCC, 2012, Box 2.7
Petroleum	0.7	India's Second National Communication to the UNFCCC, 2012, Box 2.7
Dairy	3	India's Second National Communication to the UNFCCC, 2012, Box 2.7
Meat	11.7	India's Second National Communication to the UNFCCC, 2012, Box 2.7
Pulp & Paper	60 (2011) & 57 (2012)	CSE Paper Industry Report, 2013. Available at http://ipma.co.in/wp-content/uploads/2015/11/CSE-Paper-Industry-Report-2013.pdf
Rubber	26.3	India's Second National Communication to the UNFCCC, 2012, Box 2.7
Tannery	32	Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, NEERI, 2010. Available at: http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf

Assumptions:

- Wastewater generation per tonne of product would likely vary over the years, with improvements in production processes and technologies leading to reduction in wastewater generation. However, due to the lack of such updated information in the IPCC guidelines and the National Communication, and in the absence of other published literature, constant values of wastewater generated per tonne of product have been used for all the years (2007-2012) in this assessment for 11 industry sectors except for the Pulp and paper sector.
- A value of 162 m³ of wastewater generation per tonne of product was used in the phase-I estimates for the Pulp and Paper sector based on the 2006 IPCC Guidelines. A study conducted by CSE in 2012-13 for the sector indicates that wastewater generation has reduced to 60 m³ per tonne in 2011-12 and 57 m³ per tonne in 2012-13 due to improvements in technology, with an average annual reduction of 7.4% since 1995-96¹¹⁹. Field studies conducted by the National Productivity Council in 10 pulp and paper mills in 2005-06, in consultation with the CPCB, indicate that the wastewater discharge per tonne of product ranges from 65-100 m³ and thereby validates the findings of the CSE study. Given the significant deviation in this parameter as compared to that in the 2006 IPCC Guidelines, this parameter is updated in the phase-II emission estimates for Pulp & Paper sector. Wastewater generation for the rest of the years in the reporting period has been estimated using the average annual reduction rate of 7.4%.

3. Degradable organic component in industrial wastewater (COD_i)

The following data sources are used, in the order of preference to prioritize the use of country specific values for this coefficient (based on the availability of information)

- NEERI documentation on the National Inventory (indicated in the following Table)
- NEERI documentation on Methane Emissions from wastewater in India (indicated in the following Table)
- 2006 IPCC Guidelines (Vol. 5, Chapter 6: Wastewater Treatment and Discharge)

Specific values of degradable organic concentration in the wastewater (kg COD/m³) used in the India's National Communications are not indicated in the National Communication reports. Default and country specific values are used for this coefficient in this assessment are indicated in the Table 43 below.

Table 43: Industry-wise degradable organic concentration in the Wastewater

INDUSTRY	COD (KG COD/M ³)	REFERENCE
Iron & Steel	0.55	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean Development Mechanisms in India. Published in the TERI Information Digest on Energy and Environment, [S.I.], p. 155-166, June. 2010. ISSN 0972-6721. Available at: http://www.i-scholar.in/index.php/tidee/article/view/89982
Fertilizer	3.0	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean

¹¹⁹ The CSE study includes a sample survey of twelve pulp and paper mills accounting for 21 per cent of the total production of the industry and spread over 10 states. CSE Paper Industry Report, 2013. Available at <http://ipma.co.in/wp-content/uploads/2015/11/CSE-Paper-Industry-Report-2013.pdf>

INDUSTRY	COD (KG COD/M ³)	REFERENCE
		Development Mechanisms in India. TERI Information Digest on Energy and Environment, [S.I.], p. 155-166, June 2010. ISSN 0972-6721. Available at: http://www.i-scholar.in/index.php/tidee/article/view/89982
Beer	2.9	2006 IPCC guidelines for National Greenhouse Gas Inventories, Vol.5, Chapter 6: Wastewater Treatment and Discharge, Table 6.9
Sugar	2.5	Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, NEERI, 2010. Available at: http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf
Coffee	9	2006 IPCC guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.9. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
Soft Drink	9 ¹²⁰	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean Development Mechanisms in India. Published in TERI Information Digest on Energy and Environment, [S.I.], p. 155-166, jun. 2010. ISSN 0972-6721. Available at: http://www.i-scholar.in/index.php/tidee/article/view/89982
Petroleum Refineries	1	2006 IPCC guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.9. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
Dairy	2.24	Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, NEERI, 2010. Available at: http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf
Meat	4.1	2006 IPCC guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.9
Pulp & Paper	5.9	Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, NEERI, 2010. Available at: http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf
Rubber	6.12	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean Development Mechanisms in India. Published in TERI Information Digest on Energy and Environment, [S.I.], p. 155-166, jun. 2010. ISSN 0972-6721. Available at: http://www.i-scholar.in/index.php/tidee/article/view/89982
Tannery	3.1	Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, NEERI, 2010. Available at: http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf

4. Methane Correction Factor and Emission Factor (EF_i) for the industry

The value of the MCF is based on the prevalent wastewater treatment system used in the respective industrial sector (see Table 40). The following data sources are used, in the order of preference (based on the availability of information) for consistency with India's National Communication and the IPCC guidelines

1. India's Second National Communication to the UNFCCC
2. 2006 IPCC Guidelines (Vol. 5, Chapter 6: Wastewater Treatment and Discharge)
3. Sector-specific documents and studies (used where information is not available from NEERI and IPCC guidelines)

The data sources to identify the prevalent wastewater treatment technologies for the industrial sectors and the corresponding emission factor used are indicated in Table 44.

Table 44: Industry-wise Methane Correction Factor based on the prevalent treatment system

INDUSTRY	B ₀ (KG CH ₄ /KG COD) ¹²¹	MCF ¹²²	EF= B ₀ x MCF (KG CH ₄ /KG COD)	REFERENCE FOR PREVALENT TREATMENT TECHNOLOGY
Iron & Steel	0.25	0	0	Sirajuddin, Ahmed, Umesh Chandra, R. K. Rathi, (2010) "Waste water treatment technologies Commonly practiced in

¹²⁰ COD value listed for beverages and not for soft drinks specifically

¹²¹ B₀ value is taken as default value as per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Section 6.2.3.2.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

¹²² MCF value is taken based on treatment systems listed in 2006 IPCC Guidelines, Vol. 5, Chapter 6, Table 6.8 (see Table 40 in this note). Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

INDUSTRY	Bo (KG CH ₄ /KG COD) ¹²¹	MCF ¹²²	EF= Bo x MCF (KG CH ₄ /KG COD)	REFERENCE FOR PREVALENT TREATMENT TECHNOLOGY
				Major Steel Industries in India” In 16th Annual International Sustainable Development Research Conference 2010, 30 May – 1 June, 2010 The University of Hong Kong, Hong Kong. Available at: http://www.academia.edu/26045473/Wastewater_Treatment_Technologies_Commonly_Practised_in_Major_Steel_Industries_in_India_Theme_Global_and_national_policy_processes_on_sustainable_development
Fertilizer	0.25	0.2	0.05	India's Second National Communication to the UNFCCC, 2012, Table 2.21. Available at: http://unfccc.int/resource/docs/natc/indnc2.pdf
Beer	0.25	0.8	0.2	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
Sugar	0.25	0.8	0.2	- India's Second National Communication to the UNFCCC, 2012, Table 2.21. Available at: http://unfccc.int/resource/docs/natc/indnc2.pdf - Methane extraction from Organic wastewater, at Mandya District, Karnataka< India by M/s Sri Chamundeswari Sugars Ltd https://cdm.unfccc.int/Projects/DB/DNV-CUK1176804855.99/view
Soft Drink	0.25	0.8	0.2	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
Coffee	0.25	0.8	0.2	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
Petroleum Refineries	0.25	0	0	Technical EIA Guidance Manual for Petroleum Refining Industry prepared by IL&FS Ecosmart Limited for MoEF, 2010. Available at: http://envfor.nic.in/sites/default/files/TGM_Petroleum_Refineries_010910.pdf
Dairy	0.25	0.8	0.2	India's Second National Communication to the UNFCCC, 2012, Table 2.21. Available at: http://unfccc.int/resource/docs/natc/indnc2.pdf
Meat	0.25	0.8	0.2	2006 IPCC guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
Pulp & Paper	0.25	0.8	0.2	- India's Second National Communication to the UNFCCC, 2012, Table 2.21. Available at: http://unfccc.int/resource/docs/natc/indnc2.pdf - Methane recovery from wastewater generated at Paper manufacturing unit of Sree Sakthi Paper Mills Ltd., Kerala, India https://cdm.unfccc.int/Projects/DB/SGS-UKL1236761076.31/view
Rubber	0.25	0	0	Central Pollution Control Board (CPCB), Pollution Control Implementation Division – III report on ‘Pollution Control in Natural Rubber Processing Industry’. Available at: http://cpcb.nic.in/divisionsofheadoffice/pci3/pci3divrubber.pdf

INDUSTRY	Bo (KG CH ₄ /KG COD) ¹²¹	MCF ¹²²	EF= Bo x MCF (KG CH ₄ /KG COD)	REFERENCE FOR PREVALENT TREATMENT TECHNOLOGY
				Woodard, F. (2001). Industrial waste treatment handbook. Available at: http://neerienviis.nic.in/pdf/publications/e-book/Industrial%20Waste%20Treatment%20Handbook.pdf
Tannery	0.25	0.2	0.05	India's Second National Communication to the UNFCCC, 2012, Table 2.21. Available at: http://unfccc.int/resource/docs/natc/indnc2.pdf

5. Methane Recovery Rates

CH₄ is recovered in some of the industries such as sugar, beer and dairy for energy purposes. In such cases, the methane recovered is to be subtracted from the total CH₄ estimated to be emitted from wastewater treatment in these industries. Methane recovery rates have been taken as per India's Second National Communication¹² wherein estimates have been prepared for year 2007 as follows:

- Sugar: 70% methane recovery rate
- Beer: 75% methane recovery rate
- Dairy: 75% methane recovery rate

3.6.3 Uncertainties

Emission estimate uncertainties are considerable in the case industrial waste water. Key factors that result in such significant uncertainties include:

- **Ambiguity in production data of various sub-classes of products in each industry type:** In the tier I approach adopted for industrial wastewater, waste water generation is directly proportional to the quantum of product produced. Primary sources of data such as the ASI and industry associations published information, have listed production numbers in disparate units which cannot be converted to the single metric required for computing emissions (i.e. 'tonnes' of production), since the unit conversions are not evident, nor are they published. This is relevant particularly in the case of Beer and Soft drinks sectors, wherein industrial production data collated by the ASI is available in multiple units of measurement and thereby cannot be directly used in emission calculations. Therefore, the ASI dataset has not been used to source activity data for Beer and Soft Drink sectors and the Indiatat¹²³ database has been used to obtain production data instead for these two sectors. It is also seen that there is no consistency in the data that is being reported by official datasets for industrial sectors across the years, with significant spurts and dips observed in production data that cannot be correlated to any of the then prevalent industry environment. Since, the data sources report data that is collated from numerous sources; therefore, errors in reporting from the universe of respondents are carried over into the emission estimates.
- **The operational status of industrial wastewater treatment:** The type of waste water treatment considered in the estimates is based primarily on information from NATCOM reports, 2006 IPCC guidelines⁵⁶ and NEERI publications. However, the state of the treatment plants, whether fully functional or not, is not recorded for any of the considered years. The amount of total degradable organic carbon (TOW) in industrial wastewater that is discharged into open or closed domestic sewers is very difficult to quantify, since information regarding the functional status of on-site treatment plants is not available.
- In the case of industrial wastewater, it is likely that wastewater generation per tonne of product and therefore, wastewater generation may vary over the years with changes in production processes and technologies. However, due to the lack of such updated information, constant values of wastewater generated per tonne of product have been used for all the years (2005-2013) in the emission estimates GHG Platform - India.

As per 2006 IPCC Guidelines¹²⁴, the following conclusions may be drawn regarding uncertainty of GHG emissions from the treatment and disposal of industrial waste water:

- Uncertainty resulting from values considered for Maximum CH₄ producing capacity (Bo): ±30%

¹²³ Available at <https://www.indiatat.com/default.aspx>

¹²⁴ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.10. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

- Uncertainty resulting from values considered for Industrial Production: $\pm 25\%$
- Uncertainty resulting from kg COD per unit of produced product: -50%, +100% (a factor of 2)

Sensitivity Analysis for considered MCF values

The MCF considered in the GHG estimates and possible alternate scenarios are given in the Table 45 below. Alternate scenarios are proposed based on potential alternate treatment methods that may exist on ground. Given that the exact treatment process is not validated in the Second National Communication Report¹² and given that detailed references to prevalent treatment systems are not given in other literature, the following two scenarios are considered to assess the percentage of deviation from the considered estimates.

Scenario 1 assumes that in Iron & Steel, Petroleum refineries, and Rubber industries the aerobic treatment plants for wastewater are not well managed, thereby, the MCF is changed from 0 to 0.3. In scenario 2, the impact of using anaerobic reactors instead of anaerobic shallow lagoons is considered for Tannery and Fertilizer industries.

Table 45: Alternate Scenarios for MCF values in the Industrial Wastewater Emission Estimates

INDUSTRY SECTOR	TREATMENT TYPE CONSIDERED IN GHG PLATFORM INDIA FINAL ESTIMATES	MCF	TREATMENT TYPE: ALTERNATE SCENARIO - 1	MCF - SCENARIO 1	TREATMENT TYPE: ALTERNATE SCENARIO - 2	MCF - SCENARIO 2
Iron & Steel	Aerobic well-managed	0	Aerobic not-well managed	0.3	Aerobic well-managed	0
Fertilizer	Anaerobic shallow lagoon	0.2	Anaerobic shallow lagoon	0.2	Anaerobic reactor	0.8
Petroleum Refineries	Aerobic well-managed	0	Aerobic not-well managed	0.3	Aerobic well-managed	0
Rubber	Aerobic well-managed	0	Aerobic not-well managed	0.3	Aerobic well-managed	0
Tannery	Anaerobic shallow lagoon	0.2	Anaerobic shallow lagoon	0.2	Anaerobic reactor	0.8

Table 46: Deviation in Industrial Wastewater GHG emission results based on Sensitivity Analysis

YEAR	GHG PLATFORM INDIA FINAL EMISSION ESTIMATES (MIL. TONNES OF CO ₂ e)	PERCENT DEVIATION W.R.T. CONSIDERED GHG PLATFORM INDIA FINAL EMISSION ESTIMATES	
		SCENARIO 1	SCENARIO 2
2005	17.33	21.7%	7.7%
2006	16.90	25.9%	8.1%
2007	16.57	28.6%	7.3%
2008	16.21	27.0%	6.4%
2009	16.01	18.1%	4.4%
2010	17.84	24.0%	5.5%
2011	18.62	20.6%	4.5%
2012	19.20	29.0%	5.8%
2013	21.03	34.9%	6.8%

3.6.4 Source Category specific QA/QC

The internal QC procedures outlined previously in 'GHG estimation preparation, data collection, process and storage' in section 1.3 are carried out for this source category. Specific considerations for the industrial wastewater treatment and discharge category, in view of the emission estimation approach, are indicated below. Inputs were also received from experts from NEERI and CPCB on prevalent wastewater treatment technologies for industry sectors such as Iron & Steel, Rubber, Petroleum, Beer, Dairy, Soft drinks, Coffee, Meat that are considered in this assessment. Discussions were also held with representatives from industrial departments and associations including the Ministry of Statistics and Programme Implementation, Central Board of Excise and Customs - Central Excise, the Central Pulp & Paper Research Institute, All India Brewers Association, and the Rubber Board on industrial production datasets. Inputs received helped to ascertain the status of available state-level industrial production data and gaps therein and identify potential data sources for Beer, Soft drinks, Pulp & Paper, and Rubber sectors in particular.

The emission estimates for industrial wastewater are based on a tier I approach and cover 12 industry sectors. Activity data on industrial production has been sourced from official publications from government departments, nodal agencies, and industry associations. In cases where information on industrial production for a sector has been reported in multiple datasets, the datasets have been compared and data has been sourced to minimize reliability related issues such as consistency in time-series trends, errors in conversion and reporting of units, etc. Country specific wastewater generation rates have been used for all 12 sectors. Country specific values of Degradable organic concentration in the wastewater (kg COD/m³) have been used for 8 sectors, with IPCC default values used otherwise. Limited availability of published data on facility-specific industrial wastewater generation and characteristics technology is a challenge in the source specific QA/QC for this category.

3.6.5 Recalculation

The emission estimates from phase-I have been recalculated for the five industry sectors of Pulp and Paper, Sugar, Coffee, Beer and Soft Drink as indicated in the following sections.

Pulp & Paper

As indicated earlier, the wastewater generation per tonne of product has been updated in the estimates for 2005-2013 based on a CSE study conducted in 2013 which indicates significant reduction in wastewater generation¹²⁵. Field studies conducted by the National Productivity Council in 10 pulp and paper mills in 2005-06, in consultation with the CPCB, indicate that the wastewater discharge per tonne of product ranges from 65-100 m³ and thereby, validates the findings of the CSE study. Thus, the wastewater generation per tonne of product has been updated based on the recent CSE study as indicated in Table 47.

Table 47: Comparison of Wastewater generation per tonne of product and GHG emission estimation in phase- I and phase-II for Pulp & Paper Sector

YEAR ⁸⁸	WASTEWATER GENERATION PER TONNE OF PRODUCT (CU. M PER TONNE)		GHG EMISSION (MIL. TONNES OF CO ₂ e)		PERCENT DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES
	PHASE-I	PHASE- II	PHASE-I	PHASE- II	
2007	162	79.83	29.25	14.42	-50.7%
2008	162	74.33	30.36	13.93	-54.1%
2009	162	69.21	31.81	13.59	-57.3%
2010	162	64.44	38.46	15.30	-60.2%
2011	162	60.00	42.95	15.91	-63.0%
2012	162	57.00	46.47	16.35	-64.8%

Sugar

The production of Sugar has been revised for the period from 2006-07 to 2012-13 on the basis of published data from the National Federation of Cooperative Sugar Factories Limited as indicated in Table 48. The production data reported by this data source is validated with data available from the Indian Sugar Mills Association¹²⁶.

Table 48: Comparison of Industrial Production data used in phase- I and phase-II for Sugar Sector

YEAR	SUGAR- INDUSTRIAL PRODUCTION (MIL. TONNES)		PERCENT DEVIATION W.R.T PHASE-I
	PHASE-I	PHASE- II	
2006-07	24.06	28.37	17.9%
2007-08	26.76	26.36	-1.5%
2008-09	26.03	14.54	-44.1%
2009-10	14.59	18.91	29.7%
2010-11	19.18	24.39	27.2%
2011-12	25.85	26.34	1.9%
2012-13	26.86	25.14	-6.4%

¹²⁵ CSE Paper Industry Report, 2013. Available at <http://ipma.co.in/wp-content/uploads/2015/11/CSE-Paper-Industry-Report-2013.pdf>

¹²⁶ Available at http://www.indiansugar.com/uploads/IBA_19_Sept_2015_Final_.pdf

Table 49: Comparison of GHG emission estimates in phase- I and phase-II for Sugar Sector

YEAR	SUGAR-GHG EMISSION (MIL. TONNES OF CO ₂ e)		PERCENT DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES
	PHASE-I	PHASE- II	
2007	0.085	0.076	-10.4%
2008	0.055	0.084	53.0%
2009	0.056	0.082	46.1%
2010	0.072	0.046	-36.6%
2011	0.81	0.060	-25.8%
2012	0.080	0.081	1.6%

Coffee

The production of Coffee has been revised for the year 2012-13 based on updated version of the statistical publication 'Database on Coffee, June/July 2016' of the Market Research & Intelligence Unit, Coffee Board, Ministry of Commerce and Industry. Industrial production data for the phase-I estimates was sourced from a previous version of the same statistical publication of the Coffee Board. This has resulted in an increase in the GHG emission by 0.6% for the Coffee Sector in 2012.

Table 50: Comparison of Industrial Production data used in phase- I and phase-II for Coffee Sector

YEAR	INDUSTRIAL PRODUCTION (MIL. TONNES)		PERCENT DEVIATION W.R.T PHASE-I
	PHASE-I	PHASE- II	
2012-13	0.315	0.318	0.8%

Table 51: Comparison of GHG emission estimates in phase- I and phase-II for Coffee Sector

YEAR	GHG EMISSION (MIL. TONNES OF CO ₂ e)		PERCENT DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES
	PHASE-I	PHASE- II	
2012	0.0595	0.0599	0.6%

Beer

The phase-I emission estimates used the ASI dataset to source data on production of Beer. However, since the ASI dataset is largely a statistical reporting exercise and the data collected by the ASI is not analyzed further, inconsistencies were observed in the dataset. The production data reported in the ASI dataset for Beer is adjudged to have low reliability since it is observed to have high variation in year-on-year reported data and does not represent a consistent trend. Therefore, this activity data has been revised for the period from 2006-07 to 2012-13 as indicated in Table 52 on the basis of data from the Central Statistical Organisation that has been compiled by the Indiatat database.

Table 52: Comparison of Industrial Production data used in phase- I and phase-II for Beer Sector

YEAR	BEER- INDUSTRIAL PRODUCTION (MIL. TONNES)		PERCENT DEVIATION W.R.T PHASE-I
	PHASE-I	PHASE- II	
2006-07	0.68	0.36	-47.3%
2007-08	1.43	0.41	-71.6%
2008-09	18.26	0.45	-97.5%
2009-10	0.91	0.53	-42.0%
2010-11	2.00	0.70	-64.8%
2011-12	5.34	0.96	-82.0%
2012-13	1.70	1.15	-33.9%

Table 53: Comparison of GHG emission estimates in phase- I and phase-II for Beer Sector

YEAR	BEER-GHG EMISSION (MIL. TONNES OF CO ₂ e)		PERCENT DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES
	PHASE-I	PHASE- II	
2007	0.034	0.011	-68.3%
2008	0.385	0.012	-96.9%
2009	0.144	0.014	-90.3%
2010	0.472	0.018	-61.8%
2011	0.123	0.025	-80.1%
2012	0.072	0.030	-57.7%

Soft Drink

The phase-I emission estimates used the ASI dataset to source data on production of Soft Drinks. However, since the ASI dataset is largely a statistical reporting exercise and the data collected by the ASI is not analyzed further, inconsistencies were observed in the dataset. As in the case of the Beer sector, it is observed that the production data reported in the ASI dataset for Soft drink sector does not follow a particular trend and has high variance over consecutive years and is thereby adjudged to have low reliability. Therefore, this activity data has been revised for the period from 2006-07 to 2012-13 as indicated in Table 54 on the basis of data from the Central Statistical Organisation that has been compiled by the Indiatat database.

Table 54: Comparison of Industrial Production data used in phase- I and phase-II for Soft Drink Sector

YEAR	SOFT DRINK- INDUSTRIAL PRODUCTION (MIL. TONNES)		PERCENT DEVIATION W.R.T PHASE-I
	PHASE-I	PHASE- II	
2006-07	32.89	0.75	-97.7%
2007-08	0.35	0.78	117.3%
2008-09	29.38	0.82	-97.2%
2009-10	135.60	0.85	-99.4%
2010-11	29.74	0.72	-97.6%
2011-12	117.05	0.76	-99.4%
2012-13	6.48	0.79	-87.8%

Table 55: Comparison of GHG emission estimates in phase- I and phase-II for Soft Drink Sector

YEAR	SOFT DRINK-GHG EMISSION (MIL. TONNES OF CO ₂ e)		PERCENT DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES
	PHASE-I	PHASE- II	
2007	1.19	0.11	-90.9%
2008	3.09	0.11	-96.3%
2009	15.25	0.12	-99.2%
2010	7.86	0.10	-98.7%
2011	13.32	0.10	-99.2%
2012	4.78	0.11	-97.7%

Overall Recalculation of GHG emission from Industrial Wastewater Discharge and Treatment

The emission recalculations to incorporate updated activity data of better quality for the five industry sectors have resulted in a significant decrease in the overall industrial emissions from industrial wastewater. The emission estimates have reduced by 49.0% for the year 2007 and by 64.5% in the year 2012 as compared to phase-I estimate for these years. This is largely due to the substantial changes in the calculated emissions from the Pulp and Paper sector, which contributes significantly to the industrial wastewater emissions.

Table 56: Comparison of estimates of the Total GHG emission for Industrial Wastewater Treatment and Discharge in phase- I and phase-II

YEAR	PHASE-I GHG ESTIMATES (MIL. TONNES OF CO ₂ e)	PHASE-I GHG ESTIMATES (MIL. TONNES OF CO ₂ e)	PERCENT DEVIATION W.R.T. PHASE-I GHG EMISSION ESTIMATES
2007	32.51	16.57	-49.0%
2008	36.02	16.21	-55.0%
2009	49.52	16.01	-67.7%
2010	48.76	17.84	-63.4%
2011	58.96	18.62	-68.4%
2012	54.02	19.20	-64.5%

3.6.6 Verification

An external verification of the emission estimates for this source category has not been undertaken at present. However, relevant QA/QC procedures have been applied internally to ensure reliability of calculations, processing of data, consistency, and transparent and clear documentation of methodology, assumptions and results. The emission estimates have undergone a peer review process and have been finalized subsequently.

Estimates for industrial wastewater treatment and discharge under this assessment have also been compared with the emissions reported for year 2007 and 2010 in India's National communication documents – the

Second National Communication 2012¹² and the First Biennial Update Report 2015¹³. The estimates show a deviation of -25.0% and -17.8% respectively for year 2007 and 2010 as compared to the official estimates reported by India for solid waste disposal (see Table 57).

Table 57: Comparison of the GHG emission estimates for Industrial Wastewater Treatment and Discharge with Nationally Reported Values

YEAR	EMISSION ESTIMATES FOR INDUSTRIAL WASTEWATER TREATMENT AND DISCHARGE (MIL. TONNES OF CO ₂ e)	OFFICIAL EMISSION ESTIMATES FOR INDUSTRIAL WASTEWATER TREATMENT AND DISCHARGE AS PER SECOND NATIONAL COMMUNICATION (2007) AND BIENNIAL UPDATE REPORT (2010) (MIL. TONNES OF CO ₂ e)	PERCENT DEVIATION W.R.T. OFFICIAL EMISSION ESTIMATES
2007	16.57	22.10	-25.0%
2010	17.84	21.70	-17.8%

The deviation in the estimates for this source category can be attributed largely to ambiguity over the values of multiple parameters, assumptions data sources used in official national inventories for 2007 and 2010 across the industrial sectors. The possible reasons for the deviation are discussed further below:

- **Variation in Activity Data:** The Tier I methodology for GHG emission estimation from industrial wastewater is dependent on a number of input parameters/activity data such as sector-wise production data, wastewater generation per tonne of product, COD values, and the Methane Correction Factor (based on the prevalent treatment technologies in the industry). Limited clarity and information is provided in the Second National Communication Report and the Biennial Update Report on values and specific data sources used for these parameters in the preparation of the 2007 and 2010 national inventories. While the data requirements and information gaps were addressed using appropriate data sources such as NEERI and CPCB reports/documents, however, lack of detail and clarity in the National Communication reports poses a challenge towards ensure consistency and comparability with the official National GHG estimates.
- **Data Sources:** It is not possible to use single source datasets such as the ASI in the emission estimation, due to issues such as reporting of industrial production data in multiple units of measurement and lack of requisite guidance in the ASI database for normalization/conversion of the data to a single unit (i.e. tonnes). This has necessitated use of multiple data sources for each of the industrial sectors under consideration. While nationally acceptable data sources such as the Indian Bureau of Mines, Ministry of Agriculture, Rubber Board, Fertilizers Association of India, and FAO have been used to access industrial production data, the inherent inconsistencies in these datasets have impacted the reliability of activity data and the emission estimates.
- **Factoring in Technology and Process Improvements:** It is not known if the estimates reported in the National Communication reports took into consideration the technological and process improvements; likely to impact parameters such as Wi – Wastewater production per tonne of product and Methane correction factor, which in turn would reduce wastewater generation and overall associated GHG emissions. However, due to lack of such updated information in the National Communication and Biennial Update Reports and in the absence of other documentation with relevant data, constant values of wastewater generated per tonne of product have been used for all the years (2005-2013) in this assessment, with the exception of Pulp and Paper sector.
- **Treatment Technology:** In this assessment the condition of aerobic treatment systems for Iron & Steel, Petroleum and Rubber industries is assumed to be well managed, and thereby these systems have MCF value as 0 and emission factor of 0 (see Table 42), leading to no CH₄ emissions from wastewater treatment in these sectors. The assumptions considered in the National Communication reports in this regard are not reported and this could be a possible case of deviation in the estimates.

3.6.7 Planned improvements

Constant values of wastewater generated per tonne of product have been used for all the years (2005-2013) for 11 of the 12 industry sectors considered in the emission estimates. In practice, the volume of wastewater generated per unit product should be expected to reduce given the improvements in technology and industrial processes. However, such information is not available for the industry sectors, with the exception of the Pulp & Paper sector. Updated information on changes in wastewater generation due to improved technology is sought across the industry sectors in order to accurately capture any ensuing impacts on emission.

Updated sector-wise information is also sought on volume of industrial wastewater generated and its characteristics, prevalent treatment technologies, methane recovery to improve accuracy and better represent the on-ground situation. Due to the lack of reported data on volume of industrial wastewater generated by each industry sector, a tier I approach which uses industrial production as a metric to estimate volume of wastewater generation has been adopted in the emission estimation. However, issues exist in availability, reliability, quality and usability of reported activity data on industrial production. In some cases, production data reported for the same sector across different data sources is observed to be inconsistent while reliable information for sectors such as Beer and Soft Drinks is lacking in the public domain. Production data is also found to be reported in disparate units. Access to better quality and reliable industry related data will contribute to improving reliability of the estimates.

Going forward, the GHG Platform India could look at including activities, to some extent, to collect primary data on industrial wastewater generation, its characteristics and treatment technology used by different industry sectors in order to improve reliability of the estimates. The Platform could help promote and provide technical inputs towards recording and reporting of relevant activity data in an accurate, consistent and transparent manner. The Platform could also engage further with the Ministry of Environment, Forests and Climate Change to gain access to the underlying datasets and assumptions used for the official National GHG emission estimates. This will greatly help in improving the accuracy of this assessment, enable better comparability, and help identify and address any limitations in the industrial wastewater estimates prepared under this assessment as well as official emission estimates.

4 Public Consultation & Outreach

ICLEI South Asia participated in the regional roundtable meetings organised in Bangalore, Mumbai and Delhi, to reach out to potential users of the Platform's outputs such as policymakers, research institutions, experts and the media. The round tables also aimed to capture feedback on the methodology, suitability of data sets, analyses undertaken and emission estimation results based on phase-I emission estimates. The roundtable discussions were intended to contribute to ongoing work under phase-II. Suggestions received with regard to the methodology, scope and datasets from the round tables along with relevant responses are indicated in following table. Based on feedback received from the roundtables, it was decided to expand the scope of assessment to cover rural areas as well in the phase-II domestic wastewater emission estimation.

S. N O	COMMENT	RECEIVED FROM		RESPONSE
		NAME	E-MAIL ID	
1	Atleast 5-10% of primary data can be collected in the phase II	Mr. Tapas Ghatak, Independent Waste sector Consultant	tk.ghatak@gmail.com	While collection of primary data sources can be useful, the scope of this assessment and its activities is limited to use of existing secondary data sources
2	The estimated value of the metric 'GHG emission per tonne of solid waste disposed' in the Briefing paper based on phase-I results seems too high	Prof. Amit Dutta, Jadhavpur University	Amit555@gmail.com	The computation of this metric was incorrect due to the error in unit conversion. This correction has been factored and the metric has been updated in the phase-I Briefing paper and the relevant documents and analysis for phase-II as well.
3	Models such as LandGEM model could be explored for GHG emission estimation for solid waste disposal	Prof. Amit Dutta, Jadhavpur University	Amit555@gmail.com	The emission estimation is sought to be consistent with the IPCC methodology and be comparable with India's National Communication documents. Therefore the First Order Decay (FOD) model as defined in the 2006 IPCC Guidelines and used in India's National Communication reports is followed in this assessment.
4	Emissions from solid waste processing plants and reduction due to recycling should be included	- Kankana Das, Legal Initiative for Environment and Forest - Amrita Ganguly, Ernst & Young	kankana@lifeindia.org.net -	The source category '4B Biological treatment of solid waste' has not been included in the assessment to the lack of reliable data observed and the limited number of waste incineration and composting facilities for a large part of the reporting period, especially pre-2010. Recycling related emission reductions

S. N O	COMMENT	RECEIVED FROM		RESPONSE
		NAME	E-MAIL ID	
				cannot be factored in since this requires detailed and reliable product life cycle related data which is unavailable for India
5	Emissions from Industrial solid waste may also be accounted	Dr. Ashim Bhattacharya, Bengal National Chamber of Commerce and Industry	Ashimk.bhattacharya@gmail.com	The assessment is limited to disposal of municipal solid waste. Industrial solid waste is not considered in the emission estimation, given the lack of reliable information for these waste streams and in accordance with India's National Communication Reports.
6	Domestic wastewater estimates can cover rural population	- Mr. Tapas Ghatak, Independent Waste sector Consultant - Mr. Joydeep Gupta, Third Pole	tk.ghatak@gmail.com; joydeep.gupta@thethirdpole.net	This suggestion has been considered and the scope of estimation in phase-II has been expanded to include domestic wastewater for the rural population as well.
7	Emissions from fertilizers and pesticides which are flowing in the wastewater stream can be considered.	Kankana Das, Legal Initiative for Environment and Forest	kankana@lifeindia.org.net	Direct emissions from fertilizers and pesticides application are accounted under AFOLU sector. The 2006 IPCC Guidelines ⁸⁶ indicate that indirect N ₂ O emissions are largely from covered by wastewater treatment effluent, associated with domestic sources (and any industrial wastewater co-discharged), that is discharged into water bodies. Emissions from fertilizers/pesticides are not indicated as major sources of wastewater related emission in the IPCC Guidelines.
8	Wastewater generated from Thermal Power plants can be considered in the assessment	- Dr. Ashim Bhattacharya, Bengal National Chamber of Commerce and Industry - Kankana Das, Legal Initiative for Environment and Forest	Ashimk.bhattacharya@gmail.com; kankana@lifeindia.org.net	While thermal power plants do discharge significant volumes of wastewater, this primarily contains metals (lead, mercury, cadmium and chromium) and does not contain much organic content, which contributes to GHG emission. Therefore, this industry sector is not considered
9	Resources such as Toxic Links website can be referred to for information	Prof. Sadhan Ghosh, Jadhavpur University	sadhankghosh@gmail.com	The Toxic links website is a good resource for information and case studies mainly on hazardous waste, bio-medical waste, electronic waste, plastic waste. However, while these wastes are toxic, they do not contribute to GHG emissions.
10	Environment clearances issued to industries should be referred to as data source for industrial wastewater	Manas Dey, Greentech Management Pvt. Ltd.	Mdey09@gmail.com	Limited information is available on state pollution control board websites related to environmental clearances for separate product category. The information indicated relates to cumulative wastewater generation for a mix of industries/product and it is difficult to correlate this to a per unit product basis for each product type.

5 Recommendation

The unavailability of published country-specific and regularly updated information on the activity data, emission factors and related coefficients has been a challenge in the emission estimation process for all 3 source-categories in the Waste sector. The limited availability of reliable data and specific emission factors for India has necessitated the use of the IPCC default values to a considerable extent in the emission estimates.

For instance, year-on-year information on the distribution of domestic wastewater treatment facilities is lacking which presented a challenge in accurately capturing any impacts on emission due to on-ground deployment of such systems in urban and rural areas. Furthermore, annually reported and comprehensive information on the status and performance of all sewage treatment plants in India is lacking. This makes it difficult to factor in considerations on volumes treated, underutilization of treatment capacity, quality of treatment, and recovery of methane in the emission estimates for domestic wastewater treatment and discharge.

With regard to industrial wastewater, information on volume and characteristics of industrial wastewater generated by industry sectors along with treatment technologies used and their performance is lacking. Issues exist in availability, reliability and quality of activity data related to industrial production data. There is scope to improve consistency of industry production numbers reported by primary data sources. The ASI is one of India's largest, and the most comprehensive survey system established by the MOSPI for the manufacturing sector. However, industrial output/production data collated and reported under the ASI is represented in disparate units such as tonnes, cubic meter, nos., liters, bags, pairs, rolls, bottles etc. This diversity in reported metrics makes it challenging to convert such industrial production data into the single metric of 'tonnes' that is required to calculate GHG emissions from industrial wastewater. Information on changes in specific wastewater generation per unit industrial product due to expected improvements in technology is not recorded and therefore ensuing impacts do not reflect in the emission estimates. Updated and reliable data on solid waste generation, changes in composition, operational status of processing/treatment facilities is not available, leading to approximations that impact accuracy of the emission estimates.

There is therefore a need for periodic reporting on the data points indicated above. Transparent and robust data management systems can improve accuracy of emission estimation and capture emission reduction because of policy and programme initiatives. To optimize efforts, specific data gathering and data disaggregating processes may be integrated within existing and ongoing processes that may need further strengthening.

- For example, the annual reporting by SPCBs and under the Swachh Bharat Mission needs to be strengthened and expanded to include solid waste composition along with updated status of operational and non-operational solid waste processing plants. This will help to accurately assess the waste going to disposal sites and generating GHG emissions.
- In addition, wastewater treatment status reports by the CPCB should include information on the operational status and type of wastewater treatment technologies being used. This will help to capture updated status of technological improvements and functionality and thereby improve accuracy of the emission estimates. Reporting on associated activities that is collated by Ministries, such as the information on wastewater collection and treatment facilities collated under the AMRUT scheme could also be considered to capture accurate activity data.
- A few revisions in the ASI methodology and subsequent assimilation of its information in inventory calculations could even help the MOEFCC moving up in the tier ladder. The merit in the use of ASI data sets has already been demonstrated in the emission estimates prepared for the manufacturing sector under the GHG Platform – India. The ASI could prove to be a useful information source for industrial wastewater generation, and hence, estimation of associated GHG emission. However, this is restricted by industrial output data in the ASI datasets not being in the requisite metric (i.e. tonnes) to help compute accurate emissions from industrial wastewater. The ASI can promote reporting in metrics that better conform to accurate GHG emission estimation. For example, production of beverages is better reported in volume basis (liters/kiloliters) instead of 'no. of bottles' or production of fertilizers can be reported on mass basis (kg/tonnes) instead of 'no. of bags'. It is also prudent to tap into the knowledge-base and networks of technical institutes and industry associations such as the Central Food Technological Research Institute, the Central Leather Research Institute, the Fertilizer Association of India, and the Indian Beverage Association by involving them in development of technical guidance and resources for standardization and conversion of reported metrics for products of industry sectors such as Tannery, Leather, Fertilizers, Soft Drinks, Beer etc.
- In addition, the SPCBs could also make available the data on volume of wastewater generated, its physio-chemical characteristics such as COD, and treatment processes used that is collected from all the registered industries within their jurisdiction, particularly for industry sectors such as Pulp & paper, Coffee, Soft drink, Beer, Meat, Tannery that generate substantial volumes of organic wastewater. It is also critical to enhance reliability and consistency of such data in terms of time-series trends and reported metrics, and providing sufficiently disaggregated data that enables identification of product sub-classes, technology variations, and scale of operation across the industry sectors.

6 Annexures

6.1 Classification and Degree of Utilization for Domestic Wastewater Treatment and Discharge

Figure 18: Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Urban Low Income Group in India

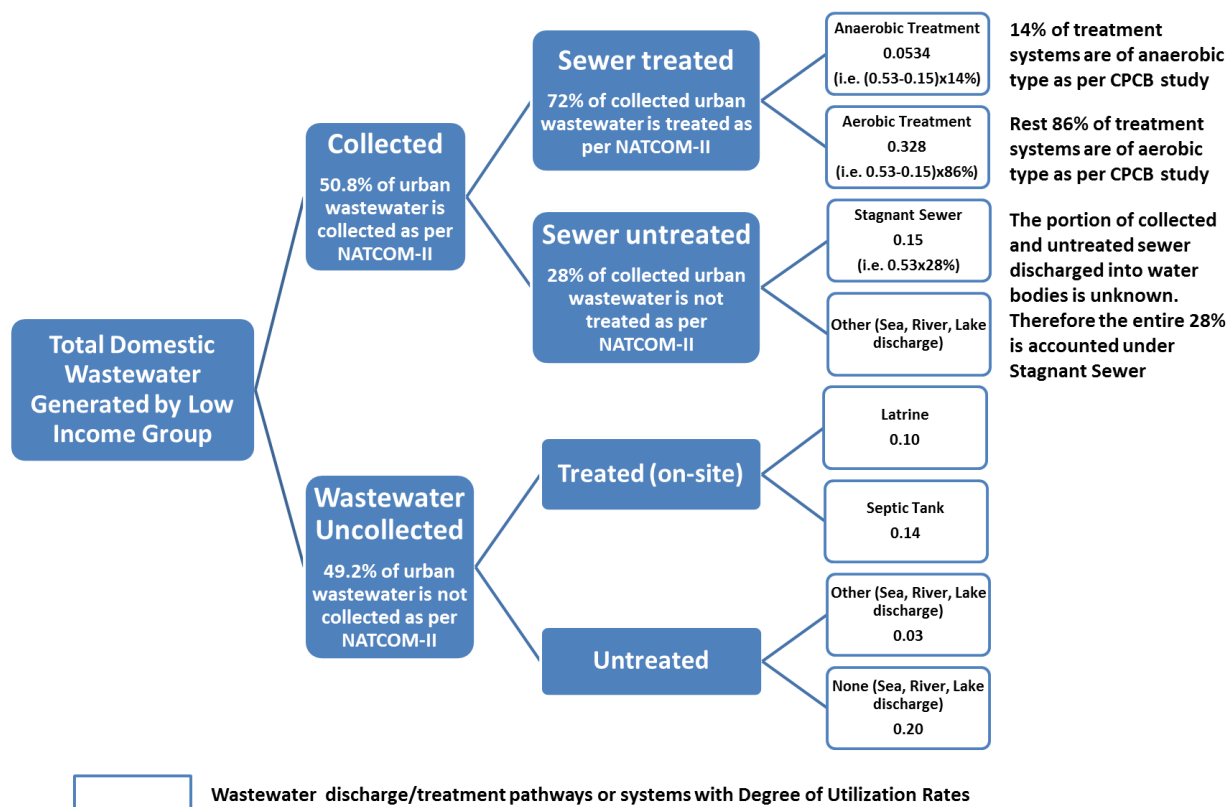
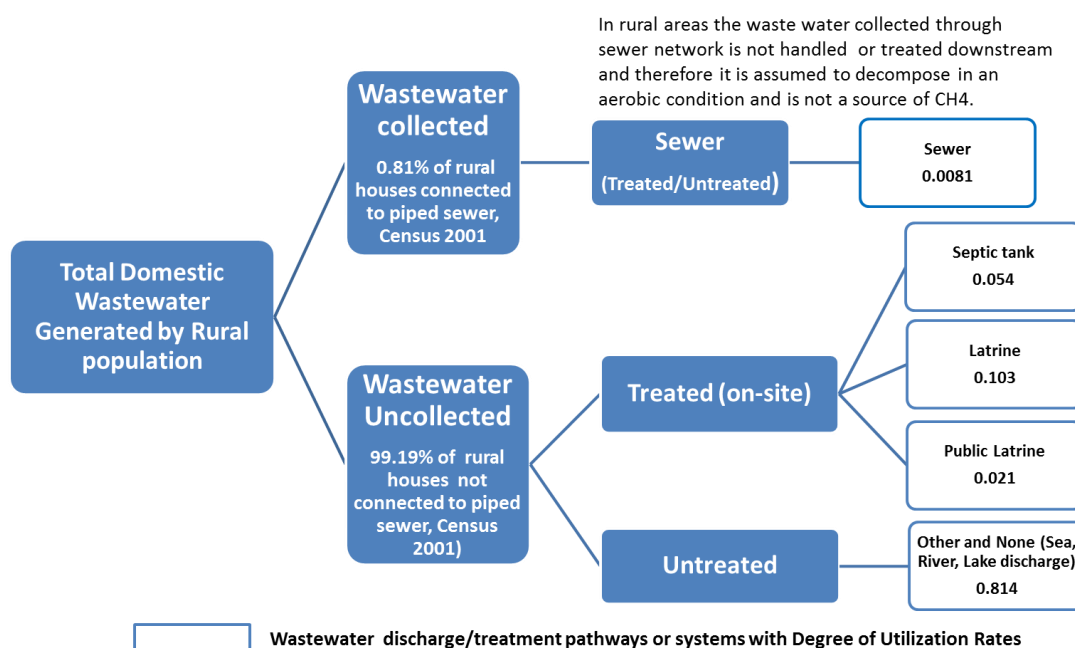


Figure 19: Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Rural India, 2001



6.2 Sample Calculations for Emission Estimation

6.2.1 Sample Emission Estimate Calculation for 4A2 Unmanaged Waste Disposal Sites for Year 2005

CH₄ Emission from Solid Waste Disposal Sites

$$\text{CH}_4 \text{ Emissions} = [\sum \text{CH}_4 \text{ generated}_T - R_T] \times (1 - \text{OX}_T) \text{ ----- Equation 1}$$

Where,

CH₄ Emissions = CH₄ emitted in year T, Gg
 T = inventory year
 x = waste category or type/material
 R_T = recovered CH₄ in year T, Gg (default value of 0¹²⁷)
 OX_T = oxidation factor in year T, (fraction) (default value of 0¹²⁸)

CH₄ Generated from Decayed DDOC_m

$$\text{CH}_4 \text{ generated}_T = \text{DDOC}_{\text{mdecomp}T} \times F \times 16/12 \text{ ---Equation 2}$$

Where,

CH₄ generated_T = amount of CH₄ generated from decomposable material
 DDOC_{m decompT} = Decomposable Degradable Organic Carbon decomposed in year T, Gg
 F = fraction of CH₄, by volume, in generated landfill gas (fraction) (default value of 0.5¹²⁹)
 16/12 = molecular weight ratio CH₄/C (ratio)

DECOMPOSABLE DOC FROM WASTE DISPOSAL DATA¹³⁰

$$\text{DDOC}_m = W \times \text{DOC} \times \text{DOC}_f \times \text{MCF} \text{ ---Equation 3}$$

Where,

DDOC_m = mass of decomposable DOC deposited, Gg
 W = mass of waste deposited, Gg
 DOC = degradable organic carbon in the year of deposition, fraction, Gg C/Gg waste
 DOC_f = fraction of DOC that can decompose (fraction) (Default value of 0.5¹²⁹)
 MCF = CH₄ correction factor for aerobic decomposition in the year of deposition (fraction) (default value of 0.4¹³¹)

ESTIMATED DOC USING DEFAULT CARBON CONTENT VALUES¹³²

$$\text{DOC} = \sum_i (\text{DOC}_i \times W_i) \text{ ---Equation 4}$$

Where,

DOC = fraction of degradable organic carbon in bulk waste, Gg C/Gg waste
 DOC_i = fraction of degradable organic carbon in waste type i¹³³
 W_i = fraction of waste type i by waste category

DDOC_m ACCUMULATED IN THE SWDS AT THE END OF YEAR T¹³⁴

$$\text{DDOC}_{\text{ma}T} = \text{DDOC}_{\text{md}T} + (\text{DDOC}_{\text{ma}T-1} \times e^{\Lambda(-k)}) \text{ ---Equation 5}$$

DDOC_m DECOMPOSED AT THE END OF YEAR T¹³⁵

¹²⁷ As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Section 3.2.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹²⁸ As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.2.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹²⁹ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹³⁰ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.2.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹³¹ As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.1.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹³² As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.7.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹³³ Default values given in 2006 IPCC Guidelines, Vol. 5, Chapter 2: Waste Generation, Composition and Management Data, Table 2.6. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹³⁴ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.4.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

$$\text{DDOC}_{\text{mdecompT}} = \text{DDOC}_{\text{maT-1}} \times (1 - e^{(-k)}) \text{---Equation 6}$$

Where,

- T = inventory year
 DDOC_{maT} = DDOCm accumulated in the SWDS at the end of year T, Gg
 $\text{DDOC}_{\text{maT-1}}$ = DDOCm accumulated in the SWDS at the end of year (T-1), Gg
 DDOC_{mdT} = DDOCm deposited into the SWDS in year T, Gg
 $\text{DDOC}_{\text{m decompT}}$ = DDOCm decomposed in the SWDS in year T, Gg
k = reaction constant,
 $k = \ln(2)/t_{1/2} \text{ (y-1)} = 0.17^{136}$
 $t_{1/2}$ = half-life time (y)¹³⁷

Step I: Calculation of per capita waste generation rates and mass of waste deposited (W)

Based on the 2006 IPCC Guidelines for National GHG Inventories¹⁵, the FOD model is used to estimate emissions from decomposition of solid waste in waste disposal sites in this assessment. The FOD model considers that waste deposited in a disposal site at a point of time decomposes gradually over time and the residual waste (material that remains after the partial decomposition of waste during anaerobic digestion process) continues to undergo anaerobic digestion again and generate CH₄ over a subsequent period of time (around 50 years). The FOD model estimates the actual methane generation at a given point of time, accounting for the total methane generation over a preceding time period. Thereby it is necessary to estimate 50-year data on waste disposal prior to the base year 2005 i.e. from 1954-2004.

As time series data on mass of waste deposited (W) for the 50-year period before 2005 is not available for India, the quantum of waste deposited in disposal sites is estimated based on urban population, per capita waste generation, and the proportion of generated waste that reaches disposal sites and leads to CH₄ emission as shown in the sample calculation that follows.

Based on reported data on per capita waste generation rates, the annual growth rate of per capita waste generation is calculated as shown in Table 58.

Table 58: Calculation of growth rates for per capita waste generation based on reported data

YEAR	REPORTED DAILY PER CAPITA WASTE GENERATION (KG/DAY) ¹³⁸	CALCULATED ANNUAL GROWTH RATE ¹³⁹
1951	0.305	1.15%
1961	0.340	1.03%
1971	0.375	1.47%
1981	0.430	0.70%
1991	0.460	1.22%
2007	0.550	1.22% ¹⁴⁰

Calculation of mass of Waste deposited W

Year 1954

- Total urban population for India = 67,391,577 persons¹⁴¹
- Applicable annual growth rate for per capita waste generation from Table 58= 1.15%

¹³⁵ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.5.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹³⁶ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Table 3.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹³⁷ As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Table 3.4.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

¹³⁸ TERI (1998): Looking Back to Think Ahead: Green India 2047'. The publication includes per capita waste generation data from NEERI and CPCB which has been used for 1951-1991. The per capita waste generation for 2007 is based on India's Second National Communication Report which is available at: <http://unfccc.int/resource/docs/natc/indnc2.pdf>

¹³⁹ Annual Growth rates have been estimated based on per capita generation rates reported for certain years as given in the Table 58 and have been used in the emission estimation to calculate per capita generation rates for the intervening years.

¹⁴⁰ The annual growth rate of 1.2% estimated based on data for 1991 and 2007 has been used to calculate per capita generation rates from 2005-2014.

¹⁴¹ Estimated based on urban population for year 1951 and annual growth rate of 2.64% calculated based on decadal growth rate from 1951-1961 as per Census of India data.

- Reported per capita waste generation, 1951 from Table 58= 0.305 kg/day/person
- Estimated per capita waste generation, 1954= $0.305 \times [1 + (1.15\% \times 3)] = 0.316$ kg/day/person
- Percent of generated waste that is sent to disposal sites = 70%¹²

Mass of waste deposited, year 1954 (W_{1954})

= Total urban population x per capita waste generation x 365 days x percent of generated waste sent to disposal site

= 67,391,577 persons x 0.316 kg/day/person x 365 days x 70%

= 5,432.45 gigagram (Gg)¹⁴²

Year 1955

- Total urban population for India = 69,040,867 persons
- Applicable annual growth rate for per capita waste generation from Table 58= 1.15%
- Reported per capita waste generation, 1951 from Table 58= 0.305 kg/day/person
- Estimated per capita waste generation, 1955= $0.305 \times [1 + (1.15\% \times 4)] = 0.319$ kg/day/person
- Percent of generated waste that is sent to disposal sites = 70%¹²

Mass of waste deposited, year 1955 (W_{1955})

= Total urban population x per capita waste generation x 365 days x percent of generated waste sent to disposal site

= 69,040,867 persons x 0.319 kg/day/person x 365 days x 70%

= 5,627.14 Gg

Similarly calculated for the intermediate years up to 2005

Year 2005

- Total urban population for India = 322,519,359 persons¹⁴³
- Applicable growth rate for per capita waste generation from Table 58= 1.22%
- Reported per capita waste generation, 1991 from Table 58 = 0.460 kg/day/person
- Estimated per capita waste generation, 2005= $0.460 \times [1 + (1.22\% \times 14)] = 0.539$ kg/day/person
- Percent of generated waste that is sent to disposal sites = 70%¹²

Mass of waste deposited, year 2005 (W_{2005})

= Total urban population x per capita waste generation x 365 days x percent of generated waste sent to disposal site

= 322,519,359 persons x 0.539 kg/day/person x 365 days x 70%

= 44,394.99 Gg

Step 2: Calculation of DOC based on Waste Composition data as per Equation 4

Waste composition available across the three years of 1971, 1995 and 2005 is assumed to be applicable for adjacent time periods i.e. 1954-1994, 1995-2004 and 2005-2014 (see Table 59). Using the default values for DOC content for degradable wet waste fractions (**DOC_i**) in waste, the DOC values for the organic portion of the waste are calculated for the time periods 1954-1994, 1995-2004 and 2005-2014 as shown in Table 59.

Table 59: Calculation of DOC content value using Waste Composition data

YEAR	FRACTION OF WASTE TYPE I BY WASTE CATEGORY (W_i)			CALCULATION FOR DOC FOR OVERALL WASTE (IN FRACTION) $DOC = \sum_i (DOC_i * W_i)$	APPLICABLE TIME PERIOD CONSIDERED FOR ESTIMATED DOC VALUE
	PAPER	TEXTILES	COMPOSTABLE MATTER		
1971 ⁴⁸	4.14%	3.83%	41.24%	$(40\% \times 4.14\%) + (24\% \times 3.83\%) + (15\% \times 41.24\%) = 0.088$	1954-1994

¹⁴² 1 gigagram= 1,000,000 kg

¹⁴³ Estimated based on urban population for year 2001 and 2011 and decadal growth rate from 2001-2011 as per Census of India data. Available at http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf

YEAR	FRACTION OF WASTE TYPE I BY WASTE CATEGORY (Wi)			CALCULATION FOR DOC FOR OVERALL WASTE (IN FRACTION) $DOC = \sum_i (DOC_i * W_i)$	APPLICABLE TIME PERIOD CONSIDERED FOR ESTIMATED DOC VALUE
	PAPER	TEXTILES	COMPOSTABLE MATTER		
1995 ⁴⁸	5.78%	3.50%	41.80%	$(40\% \times 5.78\%) + (24\% \times 3.5\%) + (15\% \times 41.8\%) = 0.094$	1995-2004
2005 ⁴⁹	8.13%	4.40%	47.40%	$(40\% \times 8.13\%) + (24\% \times 4.4\%) + (15\% \times 47.4\%) = 0.114$	2005-2014
Default DOC Content values (Wet waste) in fraction (DOC _i) ¹⁴⁴	40%	24%	15%	-	-

Step 3: Calculation of decomposable DOC deposited (DDOC_m) as per Equation 3

$$DDOC_m = W \times DOC \times DOC_f \times MCF$$

Year 1954

- Mass of waste deposited (W_{1954}) = 5,432.45 Gg
- $DOC_{1954-1994} = 0.088$ Gg C/Gg waste
- $DOC_f = 0.5$
- $MCF = 0.4$

$$\begin{aligned} DDOC_{m(1954)} &= W \times DOC \times DOC_f \times MCF \\ &= 5,432.45 \text{ Gg} \times 0.088 \text{ Gg C/Gg waste} \times 0.5 \times 0.4 \\ &= 95.19 \text{ Gg C} \end{aligned}$$

Year 1955

- Mass of waste deposited (W_{1955}) = 5,627.14 Gg
- $DOC_{1954-1994} = 0.088$ Gg C/Gg waste
- $DOC_f = 0.5$
- $MCF = 0.4$

$$\begin{aligned} DDOC_{m(1955)} &= W \times DOC \times DOC_f \times MCF \\ &= 5,627.14 \text{ Gg} \times 0.088 \text{ Gg C/Gg waste} \times 0.5 \times 0.4 \\ &= 98.60 \text{ Gg C} \end{aligned}$$

Similarly calculated for the intermediate years up to 2005

Year 2005

- Mass of waste deposited (W_{2005}) = 44,394.99 Gg
- $DOC_{2005-2014} = 0.114$ Gg C/Gg waste
- $DOC_f = 0.5$
- $MCF = 0.4$

$$\begin{aligned} DDOC_{m(2005)} &= W \times DOC \times DOC_f \times MCF \\ &= 44,394.99 \text{ Gg} \times 0.114 \text{ Gg C/Gg waste} \times 0.5 \times 0.4 \\ &= 1,013.80 \text{ Gg C} \end{aligned}$$

Step 4: Calculation of DDOC_m Accumulated in the Disposal Site at the End of Year T (DDOC_{mat}) as per Equation 5

¹⁴⁴ As per 2006 IPCC Guidelines, Vol. 5, Chapter 2: Waste Generation, Composition and Management Data, Table 2.6. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

$$DDOC_{maT} = DDOC_{mdT} + (DDOC_{maT-I} \times e^{\Lambda(-k)})$$

Year 1954

- $DDOC_m (1954) = 95.19 \text{ Gg C}$
- $DDOC_{maT-I} (1953) = 0 \text{ Gg C}^{145}$
- Euler's constant $e = 2.718$
- $k = 0.17$

$$\begin{aligned} DDOC_{maT} (1954) &= DDOC_m (1954) + (DDOC_{maT-I} (1953) \times e^{\Lambda(-k)}) \\ &= 95.19 + (0 \times 2.718^{\Lambda(-0.17)}) \\ &= 95.19 \text{ Gg C} \end{aligned}$$

Year 1955

- $DDOC_m (1955) = 98.60 \text{ Gg C}$
- $DDOC_{maT-I} (1954) = 95.19 \text{ Gg C}$
- Euler's constant $e = 2.718$
- $k = 0.17$

$$\begin{aligned} DDOC_{maT} (1955) &= DDOC_m (1955) + (DDOC_{maT-I} (1954) \times e^{\Lambda(-k)}) \\ &= 98.60 + (95.19 \times 2.718^{\Lambda(-0.17)}) \\ &= 178.91 \text{ Gg C} \end{aligned}$$

Similarly calculated for the intermediate years up to 2005

Year 2005

- $DDOC_m (2005) = 1,013.80 \text{ Gg C}$
- $DDOC_{maT-I} (2004) = 4,226.47 \text{ Gg C}$
- Euler's constant $e = 2.718$
- $k = 0.17$

$$\begin{aligned} DDOC_{maT} (2005) &= DDOC_m (2005) + (DDOC_{maT-I} (2004) \times e^{\Lambda(-k)}) \\ &= 1,013.80 + (4,226.47 \times 2.718^{\Lambda(-0.17)}) \\ &= 4,579.59 \text{ Gg C} \end{aligned}$$

Step 5: Calculation of $DDOC_m$ Decomposed at the end of year T ($DDOC_{m \text{ decomp}T}$) as per Equation 6

$$DDOC_{mdecompT} = DDOC_{maT-I} \times (1 - e^{\Lambda(-k)})$$

Year 1954

- $DDOC_{maT-I} (1953) = 0 \text{ Gg C}$
- Euler's constant $e = 2.718$
- $k = 0.17$

$$\begin{aligned} DDOC_{mdecompT} (1954) &= DDOC_{maT-I} (1953) \times (1 - e^{\Lambda(-k)}) \\ &= 0 \times (1 - 2.718^{\Lambda(-0.17)}) \\ &= 0 \text{ Gg C} \end{aligned}$$

Year 1955

- $DDOC_{maT-I} (1954) = 95.19 \text{ Gg C}$
- Euler's constant $e = 2.718$
- $k = 0.17$

$$\begin{aligned} DDOC_{mdecompT} (1955) &= DDOC_{maT-I} (1954) \times (1 - e^{\Lambda(-k)}) \\ &= 95.19 \times (1 - 2.718^{\Lambda(-0.17)}) \\ &= 14.88 \text{ Gg C} \end{aligned}$$

¹⁴⁵ Waste disposal is considered from 1954 onwards and therefore $DDOC_m$ accumulated in 1953 is assumed to be zero

Similarly calculated for the intermediate years up to 2005

Year 2005

- $\text{DDOC}_{\text{maT-I}} (2004) = 4,226.47 \text{ Gg C}$
- Euler's constant $e = 2.718$
- $k = 0.17$

$$\begin{aligned}\text{DDOC}_{\text{mdecompT}} (2005) &= \text{DDOC}_{\text{maT-I}} (2004) \times (1 - e^{\Lambda(-k)}) \\ &= 4,226.47 \times (1 - 2.718^{\Lambda(-0.17)}) \\ &= 660.68 \text{ Gg C}\end{aligned}$$

Step 6: Calculation of CH₄ generated ($\text{CH}_{4\text{generatedT}}$) from decomposed DDOC_m as per Equation 2

$$\text{CH}_{4\text{generatedT}} = \text{DDOC}_{\text{mdecompT}} \times F \times 16/12$$

Year 1954

- $\text{DDOC}_{\text{mdecompT}} (1954) = 0 \text{ Gg C}$
- $F = \text{default value of } 0.5$

$$\begin{aligned}\text{CH}_{4\text{generatedT}} (1954) &= \text{DDOC}_{\text{mdecompT}} (1954) \times F \times 16/12 \\ &= 0 \times 0.5 \times 16/12 \\ &= 0 \text{ Gg CH}_4\end{aligned}$$

Year 1955

- $\text{DDOC}_{\text{mdecompT}} (1955) = 14.88 \text{ Gg C}$
- $F = \text{default value of } 0.5$

$$\begin{aligned}\text{CH}_{4\text{generatedT}} (1955) &= \text{DDOC}_{\text{mdecompT}} (1955) \times F \times 16/12 \\ &= 14.88 \times 0.5 \times 16/12 \\ &= 9.92 \text{ Gg CH}_4\end{aligned}$$

Similarly calculated for the intermediate years up to 2005

Year 2005

- $\text{DDOC}_{\text{mdecompT}} (2005) = 660.68 \text{ Gg C}$
- $F = \text{default value of } 0.5$

$$\begin{aligned}\text{CH}_{4\text{generatedT}} (2005) &= \text{DDOC}_{\text{mdecompT}} (2005) \times F \times 16/12 \\ &= 660.68 \times 0.5 \times 16/12 \\ &= 440.46 \text{ Gg CH}_4\end{aligned}$$

Step 7: Calculation of Total CH₄ emission from solid waste disposal sites as per Equation 1

$$\text{CH}_4 \text{ Emissions} = [\sum \text{CH}_{4\text{generatedT}} - R_T] \times (1 - \text{OX}_T)$$

Year 1954

- $\text{CH}_{4\text{generatedT}} (1954) = 0 \text{ Gg CH}_4$
- $R_T = \text{default value of } 0$
- $\text{OX}_T = \text{default value of } 0$

$$\begin{aligned}\text{CH}_4 \text{ Emissions} (1954) &= [\text{CH}_{4\text{generatedT}} (1954) - R_T] \times (1 - \text{OX}_T) \\ &= [0 - 0] \times (1 - 0) \\ &= 0 \text{ Gg CH}_4 = 0 \times 10^3 \text{ tonnes of CH}_4 \\ &= 0 \text{ tonnes of CH}_4\end{aligned}$$

Year 1955

- $\text{CH}_{4\text{generatedT}} (1955) = 9.92 \text{ Gg CH}_4$
- $R_T = \text{default value of } 0$
- $\text{OX}_T = \text{default value of } 0$

$$\begin{aligned}
 \text{CH}_4 \text{ Emissions}_{(1955)} &= [\text{CH}_{4\text{generatedT}}(1955) - R_T] \times ((1 - \text{OX}_T)) \\
 &= [9.92 - 0] \times (1 - 0) \\
 &= 9.92 \text{ Gg CH}_4 = 9.92 \times 10^3 \text{ tonnes of CH}_4 \\
 &= 9,920.04 \text{ tonnes of CH}_4
 \end{aligned}$$

Similarly calculated for the intermediate years up to 2005

Year 2005

- $\text{CH}_{4\text{generatedT}}(2005) = 440.46 \text{ Gg CH}_4$
- $R_T = \text{default value of } 0$
- $\text{OX}_T = \text{default value of } 0$

$$\begin{aligned}
 \text{CH}_4 \text{ Emissions}_{(2005)} &= [\text{CH}_{4\text{generatedT}}(2005) - R_T] \times ((1 - \text{OX}_T)) \\
 &= [440.46 - 0] \times (1 - 0) \\
 &= 440.46 \text{ Gg CH}_4 = 440.46 \times 10^3 \text{ tonnes of CH}_4 \\
 &= 440,455.49 \text{ tonnes of CH}_4
 \end{aligned}$$

Step 8: Calculation of Total CH₄ emissions from Solid Waste Disposal in tonnes of CO₂e

Total CH₄ emissions from Solid Waste Disposal in tonnes of CO₂e (2005)

= (Emission in tonnes of CH₄ × GWP of CH₄)

= 440,455.49 × 21¹⁴⁶

= 9,249,565.30 tonnes of CO₂e

6.2.2 Sample Emission Estimate Calculation for 4DI Domestic Wastewater Treatment and Discharge for Year 2005

I) Sample Calculation for CH₄ Emission from Domestic Wastewater Emission for Year 2005

Where, $\text{CH}_4 \text{ Emissions} = \sum_{i,j} [(U_i * T_{ij} * EF_j)] (TOW - S) - R$ -----Equation 7

CH₄ Emissions = Methane emissions in inventory year, kg CH₄/yr

TOW = total organics in wastewater in inventory year, kg BOD/yr

S = organic component removed as sludge in inventory year, kg BOD/yr (default value of 0¹⁴⁷)

U_i = fraction of population in income group i in inventory year

T_{ij} = degree of utilization of treatment/discharge pathway or system j, for each income group fraction i in inventory year

i = income group: rural, urban high income and urban low income

j = each treatment/discharge pathway or system

EF_j = emission factor, kg CH₄/kg BOD

R = amount of CH₄ recovered in inventory year, kg CH₄/yr (default value of 0¹⁴⁸)

The emission factor EF_j for the various type treatment system or discharge pathways is a function of the maximum CH₄ producing potential (B₀) and the corresponding methane correction factor (MCF) for the waste water treatment and discharge system.

$$\text{CH}_4 \text{ Emission Factor } EF_j = B_0 * \text{MCF}_j \text{ -----Equation 8}$$

Where,

EF_j = emission factor, kg CH₄/kg BOD

j = each treatment/discharge pathway or system

B₀ = maximum CH₄ producing capacity, kg CH₄/kg BOD (Default value 0.6¹⁴⁹)

¹⁴⁶ 100-year GWP values specified for CH₄ is 21 as per the IPCC Second Assessment Report, 1996, Technical Summary, Table 4. Available at https://www.ipcc.ch/ipccreports/sar/wg1/ipcc_sar_wg1_full_report.pdf

¹⁴⁷ As per 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

¹⁴⁸ As per 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6: Wastewater Treatment and Discharge and NEERI document on Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, 2010. Available at: <http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf>

¹⁴⁹ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.2.

MCF_j = methane correction factor (fraction)

The equation for TOW in domestic wastewater is:

$$TOW = P * BOD * 0.001 * I * 365 \quad \text{----- Equation 9}$$

Where,

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = population in inventory year, (person)

BOD = country-specific per capita BOD in inventory year, g/person/day,

0.001 = conversion from grams BOD to kg BOD

I = correction factor for additional industrial BOD discharged into sewers

Step I: Calculation of TOW as per Equation 9

- Country Population P (2005) = 1,089,610,066 persons¹⁵⁰
- BOD = 40.5 gm/person/day¹⁵¹
- I = default value¹⁵² (1.00 for uncollected wastewater; 1.25 for collected wastewater)

TOW (total country)

$$= P * BOD * 0.001 * I * 365$$

$$= 1,089,610,066 \text{ persons} \times 40.5 \text{ gm/person/day} \times 0.001 \times I \times 365 \text{ days}$$

$$= 16,107,160,807.48 \text{ kg BOD/Year}$$

TOW, collected portion of wastewater - urban

$$= \text{Total Country TOW} \times 50.8\%^{153} \text{ (collected share of wastewater for urban areas)} \times 1.25$$

$$= 16,107,160,807.48 \text{ kg BOD/Year} \times 50.8\% \times 1.25$$

$$= 10,228,047,112.75 \text{ kg BOD/Year}$$

TOW, uncollected portion of wastewater - urban

$$= \text{Total Country TOW} \times 49.2\%^{153} \text{ (uncollected share of wastewater for urban areas)} \times 1.00$$

$$= 16,107,160,807.48 \text{ kg BOD/Year} \times 49.2\% \times 1.00$$

$$= 7,924,723,117.28 \text{ kg BOD/Year}$$

TOW, uncollected portion of wastewater - rural¹⁵⁴

$$= \text{Total Country TOW} \times 65.8\% \text{ (uncollected share of wastewater for rural areas)} \times 1.00$$

$$= 16,107,160,807.48 \text{ kg BOD/Year} \times 65.8\%^{155} \times 1.00$$

$$= 10,598,511,811.32 \text{ kg BOD/Year}$$

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

¹⁵⁰ Estimated based on country population for year 2001 and 2011 and annual growth rate of 1.77% calculated based on decadal growth rate from 2001-2011 as per Census of India data. Available at http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf

¹⁵¹ NEERI document on Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, 2010. Available at: <http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf>

¹⁵² Based on 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

¹⁵³ Ministry of Environment and Forests, Government of India (2012): India - Second National Communication Report, 2012 to the UNFCCC, Page 76. Available at: <http://unfccc.int/resource/docs/natc/indnc2.pdf>

¹⁵⁴ As reported in India's Second National Communication, the waste water generated in rural areas is not handled or treated in any way and decomposes under aerobic conditions. Using this basis, the proportion of rural wastewater that is collected and conveyed through sewer systems is also assumed to not undergo any treatment downstream and decomposes under aerobic conditions, thereby not leading to CH₄ emissions. Therefore, emissions are estimated only for uncollected portion for rural domestic wastewater

¹⁵⁵ Office of the Registrar General & Census Commissioner, India, Government of India: House listing and Housing Census Data Highlights – 2011. Presentation on House listing and Housing Census Data Highlights; refer percent of households without drainage connectivity on slide 50. Available at http://censusindia.gov.in/2011census/hlo/hlo_highlights.html

Step 2: Calculation of CH₄ Emission Factor for each Treatment Discharge Pathway as per Equation 8

Table 60: CH₄ Emission factor calculation for Treatment Pathway in Urban and Rural income groups

INCOME GROUP (i)	TREATMENT/ DISCHARGE PATHWAY OR SYSTEM (j)	DEGREE OF UTILIZATION OF TREATMENT/ DISCHARGE PATHWAY OR SYSTEM j, FOR EACH INCOME GROUP FRACTION I (Ti,j) ¹⁵⁶	MCFj	Bo (KG CH ₄ /KG BOD)	EFj = Bo x MCFj (KG CH ₄ /KG BOD)
Urban – High	Septic Tank (uncollected)	0.18	0.50	0.6	0.30
	Latrine (uncollected)	0.08	0.10	0.6	0.06
	Other (uncollected and not treated)	0.07	0.10	0.6	0.06
	Sewer (collected and not treated)	0.1876	0.50	0.6	0.30
	Sewer (collected and anaerobic treatment)	0.0675	0.80	0.6	0.48
	Sewer (collected and aerobic treatment) not well managed	0.4149	0.30	0.6	0.18
	None	0	0.10	0.6	0.06
Urban – low	Septic Tank (uncollected)	0.14	0.50	0.6	0.30
	Latrine (uncollected)	0.10	0.10	0.6	0.06
	Other (uncollected and not treated)	0.03	0.10	0.6	0.06
	Sewer (collected and not treated)	0.148	0.50	0.6	0.30
	Sewer (collected and anaerobic treatment)	0.053	0.80	0.6	0.48
	Sewer (collected and aerobic treatment) not managed well	0.3281	0.30	0.6	0.18
	None	0.2	0.10	0.6	0.06
Rural	Septic Tank uncollected)	0.054	0.50	0.6	0.30
	Latrine (uncollected)	0.103	0.10	0.6	0.06
	Public Latrine (Uncollected)	0.0214	0.50	0.6	0.30
	Sewer (Open and closed drainage)	0.0081	0	0.6	0
	Other & None (Uncollected)	0.8137	0.10	0.6	0.06

Step 3: CH₄ Emission Calculation for each income Group by Treatment type as per Equation 7

$$CH_4 \text{ Emissions} = \sum_{i,j} [(U_i * T_{i,j} * EF_j)](TOW - S) - R$$

A) Urban High Income

- $U_i = 0.06$ ¹⁵⁷
- $T_{i,j}$ for different treatment/discharge pathways from Table 60 above
- EF_j for different treatment/discharge pathways from Table 60 above

CH₄ emissions from Treatment/Discharge Pathways classified as 'Uncollected'

a) CH₄ emissions from Septic tank (uncollected)
 = $(0.06 \times 0.18 \times 0.30 \text{ kg CH}_4/\text{kg BOD}) \times 7,924,723,117.28 \text{ kg BOD/Year}$
 = 24,622,497.30 kg CH₄/year

b) CH₄ emissions from Latrine (uncollected)
 = $(0.06 \times 0.08 \times 0.06 \text{ kg CH}_4/\text{kg BOD}) \times 7,924,723,117.28 \text{ kg BOD/Year}$
 = 2,188,666.43 kg CH₄/year

c) CH₄ emissions from Other (uncollected and not treated)
 = $(0.06 \times 0.07 \times 0.06 \text{ kg CH}_4/\text{kg BOD}) \times 7,924,723,117.28 \text{ kg BOD/Year}$
 = 2,471,702.81 kg CH₄/year

d) CH₄ emissions from None
 = $(0.06 \times 0 \times 0.06 \text{ kg CH}_4/\text{kg BOD}) \times 7,924,723,117.28 \text{ kg BOD/Year}$

¹⁵⁶ Please refer to Table 25 and Table 28 for details of sources and calculation of these values

¹⁵⁷ Refer to Table 23 in this note for further details

= 0 kg CH₄/year

CH₄ emissions from Treatment/Discharge Pathways classified as 'Collected'

e) CH₄ emissions from Sewer (collected and not treated)

= $(0.06 \times 0.188 \times 0.30 \text{ kg CH}_4/\text{kg BOD}) \times 10,228,047,112.75 \text{ kg BOD/Year}$
 = 33,120,817.67 kg CH₄/year

f) CH₄ emissions from Sewer (collected and anaerobic treatment)

= $(0.06 \times 0.0675 \times 0.48 \text{ kg CH}_4/\text{kg BOD}) \times 10,228,047,112.75 \text{ kg BOD/Year}$
 = 19,077,590.98 kg CH₄/year

g) CH₄ emissions from Sewer (collected and other treatment)

= $(0.06 \times 0.415 \times 0.18 \text{ kg CH}_4/\text{kg BOD}) \times 10,228,047,112.75 \text{ kg BOD/Year}$
 = 43,946,593.51 kg CH₄/year

B) Urban Low Income

- $U_i = 0.22^{157}$
- $T_{i,j}$ for different treatment/discharge pathways from Table 60 above
- EF_i for different treatment/discharge pathways from Table 60 above

CH₄ emissions from Treatment/Discharge Pathways classified as 'Uncollected'

a) CH₄ emissions from Septic tank (uncollected)

= $(0.22 \times 0.14 \times 0.30) \times 7,924,723,117.28 \text{ kg BOD/Year}$
 = 73,411,519.72 kg CH₄/year

b) CH₄ emissions from Latrine (uncollected)

= $(0.22 \times 0.10 \times 0.06 \text{ kg CH}_4/\text{kg BOD}) \times 7,924,723,117.28 \text{ kg BOD/Year}$
 = 10,487,359.96 kg CH₄/year

c) CH₄ emissions from Other (uncollected and not treated)

= $(0.22 \times 0.03 \times 0.06 \text{ kg CH}_4/\text{kg BOD}) \times 7,924,723,117.28 \text{ kg BOD/Year}$
 = 3,146,207.99 kg CH₄/year

d) CH₄ emissions from None

= $(0.22 \times 0.20 \times 0.06 \text{ kg CH}_4/\text{kg BOD}) \times 7,924,723,117.28 \text{ kg BOD/Year}$
 = 20,974,719.92 kg CH₄/year

CH₄ emissions from Treatment/Discharge Pathways classified as 'Collected'

e) CH₄ emissions from Sewer (collected and not treated)

= $(0.22 \times 0.15 \times 0.30 \text{ kg CH}_4/\text{kg BOD}) \times 10,228,047,112.75 \text{ kg BOD/Year}$
 = 100,433,524.24 kg CH₄/year

f) CH₄ emissions from Sewer (collected and anaerobic treatment)

= $(0.22 \times 0.0534 \times 0.48 \text{ kg CH}_4/\text{kg BOD}) \times 10,228,047,112.75 \text{ kg BOD/Year}$
 = 57,849,709.96 kg CH₄/year

g) CH₄ emissions from Sewer (collected and other treatment)

= $(0.22 \times 0.328 \times 0.18 \text{ kg CH}_4/\text{kg BOD}) \times 10,228,047,112.75 \text{ kg BOD/Year}$
 = 133,260,939.02 kg CH₄/year

Total Urban Domestic Wastewater CH₄ emissions (tonnes of CH₄)

= Total CH₄ emissions (Urban High-income group) + Total CH₄ emissions (Urban Low-income group) =
 ((2,46,22,497.30 + 21,88,666.43 + 24,71,702.81 + 3,31,20,817.67 + 1,90,77,590.98 + 4,39,46,593.51) +
 (7,34,11,519.72 + 1,04,87,359.96 + 31,46,207.99 + 10,04,33,524.24 + 5,78,49,709.96 + 13,32,60,939.02))/1000
 = 524,991.85 tonnes of CH₄

Total CH₄ emissions from Urban Domestic Wastewater in tonnes of CO₂e (2005)

= Emission in tonnes of CH₄ × GWP of CH₄

= 524,991.85 × 21¹⁵⁸

= 11,024,828.84 tonnes of CO₂e

¹⁵⁸ 100-year GWP values specified for CH₄ is 21 as per the IPCC Second Assessment Report, 1996, Technical Summary, Table 4. Available at https://www.ipcc.ch/ipccreports/sar/wg_1/ipcc_sar_wg_1_full_report.pdf

C) Rural

- $U_i = 0.722^{157}$
- $T_{i,j}$ for different treatment/discharge pathways from Table 60 above
- EF_j for different treatment/discharge pathways from Table 60 above

CH₄ emissions from Treatment/Discharge Pathways classified as 'Uncollected'a) CH₄ emissions from Septic tank (uncollected)

$$= (0.722 \times 0.054 \times 0.30 \text{ kg CH}_4/\text{kg BOD}) \times 10,598,511,811.32 \text{ kg BOD/Year}$$

$$= 123,488,200.02 \text{ kg CH}_4/\text{year}$$

b) CH₄ emissions from Latrine (uncollected)

$$= (0.722 \times 0.103 \times 0.06 \text{ kg CH}_4/\text{kg BOD}) \times 10,598,511,811.32 \text{ kg BOD/Year}$$

$$= 47,283,585.88 \text{ kg CH}_4/\text{year}$$

c) CH₄ emissions from Other (uncollected and not treated)

$$= (0.722 \times 0.021 \times 0.30 \text{ kg CH}_4/\text{kg BOD}) \times 10,598,511,811.32 \text{ kg BOD/Year}$$

$$= 49,119,841.64 \text{ kg CH}_4/\text{year}$$

d) CH₄ emissions from None

$$= (0.722 \times 0.814 \times 0.06 \text{ kg CH}_4/\text{kg BOD}) \times 10,598,511,811.32 \text{ kg BOD/Year}$$

$$= 373,540,328.46 \text{ kg CH}_4/\text{year}$$

CH₄ emissions from Treatment/Discharge Pathways classified as 'Collected'e) CH₄ emissions from Sewer (collected and not treated)

$$= 0 \text{ kg CH}_4/\text{year}^{159}$$

Total Rural Domestic Wastewater CH₄ emissions (tonnes of CH₄)

$$= (123,488,200.02 + 47,283,585.88 + 49,119,841.64 + 0 + 373,540,328.46)/1000$$

$$= 593,431.96 \text{ tonnes of CH}_4$$

Total CH₄ emissions from Rural Domestic Wastewater in tonnes of CO₂e (2005)

$$= \text{Emission in tonnes of CH}_4 \times \text{GWP of CH}_4$$

$$= 593,431.96 \times 21^{158}$$

$$= 12,462,071.08 \text{ tonnes of CO}_2\text{e}$$

Grand Total CH₄ emissions from Domestic Wastewater at the National-level, year 2005

$$= \text{Urban wastewater CH}_4 \text{ emission} + \text{Rural wastewater CH}_4 \text{ emission}$$

$$= 11,024,828.84 + 12,462,071.08$$

$$= 23,486,899.92 \text{ tonnes of CO}_2\text{e}$$

2) Sample Calculation for N₂O Emission from Domestic Wastewater for Year 2005

$$N_2O \text{ Emissions} = N_{EFFLUENT} * EF_{EFFLUENT} * 44/28 \text{ ----- Equation 10}$$

Where,

N₂O emissions = N₂O emissions in inventory year, kg N₂O/yrN_{EFFLUENT} = nitrogen in the effluent discharged to aquatic environments, kg N/yrEF_{EFFLUENT} = emission factor for N₂O emissions from discharged to wastewater, kg N₂O-N/kg N44/28 is used for conversion of kg N₂O-N into kg N₂O.

$$N_{EFFLUENT} = (P * Protein * F_{NPR} * F_{NON_CON} * F_{IND_COM}) - N_{SLUDGE} \text{ -----Equation 11}$$

N_{EFFLUENT} = total annual amount of nitrogen in the wastewater effluent, kg N/yr

P = human population

¹⁵⁹ As reported in India's Second National Communication, rural wastewater that is collected and conveyed through sewer systems is also assumed to not undergo any treatment downstream and decomposes under aerobic conditions, thereby not leading to CH₄ emissions.

Protein	= annual per capita protein consumption, kg/person/yr
F_{NPR}	= fraction of nitrogen in protein, kg N/kg protein (default value of 0.16 used as per 2006 IPCC guidelines for wastewater ¹⁶⁰)
$F_{NON-CON}$	= factor for non-consumed protein added to the wastewater (default value of 1.4 used as per 2006 IPCC guidelines for wastewater ¹⁶¹)
$F_{IND-COM}$	= factor for industrial and commercial co-discharged protein into the sewer system, (default value of 1.25 used as per 2006 IPCC guidelines for wastewater ¹⁶⁰)
N_{SLUDGE}	= nitrogen removed with sludge, kg N/yr (default value of 0 used as per 2006 IPCC guidelines for wastewater ¹⁶⁰)

A) N₂O Emissions from Urban Population

Step 1: Calculation of Total Nitrogen in the wastewater effluent as per Equation 11

$$N_{EFFLUENT} = (P \times \text{Protein} \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM}) - N_{SLUDGE}$$

- Urban population, 2005 = 322,519,359 persons¹⁶²
- Annual per capita protein consumption = 57 gm/person/day¹⁶³ × 365 day = 20.81 kg/capita/day
- Fraction of Nitrogen in Protein (F_{NPR}) = 0.16
- Factor for Non-consumed protein added to the wastewater ($F_{NON-CON}$) = 1.40
- Factor for industrial and commercial co-discharged protein into the sewer system ($F_{IND-COM}$) = 1.25
- Nitrogen removed with sludge (N_{SLUDGE}) = 0

Total annual nitrogen in the wastewater effluent

$$= (322,519,359 \text{ persons} \times 20.81 \text{ Kg/person/year} \times 0.16 \times 1.4 \times 1.25) - 0$$

$$= 1,878,804,275.08 \text{ kg N/Year}$$

Step 2: Calculation of N₂O emissions as per Equation 10

$$N_2O \text{ Emissions} = N_{EFFLUENT} \times EF_{EFFLUENT} \times 44/28$$

- Total annual amount of nitrogen in the wastewater effluent ($N_{EFFLUENT}$) = 1,878,804,275.08 kg N/Year
- Emission Factor for N₂O emissions from discharged to wastewater ($EF_{EFFLUENT}$) = 0.005 kg N₂O-N/kg N
- 44/28 - The factor is the conversion of kg N₂O-N into kg N₂O = 1.57

Total N₂O Emission from Domestic Wastewater (Urban) (tonnes of N₂O)

$$= (1,878,804,275.08 \text{ kg N/Year} \times 0.005 \text{ kg N}_2\text{O-N/kg N} \times 1.57)/1000$$

$$= 14,762.03 \text{ tonnes of N}_2\text{O}$$

Total N₂O Emission from Domestic Wastewater (Urban) (tonnes of CO₂e)

$$= \text{Emission in tonnes of N}_2\text{O} \times \text{GWP of N}_2\text{O}$$

$$= 14,762.03 \times 310^{164}$$

$$= 4,576,230.41 \text{ tonnes CO}_2\text{e}$$

B) N₂O emissions from Rural Population

Step 1: Calculation of Total Nitrogen in the wastewater effluent as per Equation 11

$$N_{EFFLUENT} = (P \times \text{Protein} \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM}) - N_{SLUDGE}$$

¹⁶⁰ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.8.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

¹⁶¹ As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Section 6.3.1.3.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

¹⁶² Estimated based on urban population for year 2001 and 2011 and annual growth rate of 3.18% calculated based on decadal growth rate from 2001-2011 as per Census of India data. Available at http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf

¹⁶³ Refer Table 30 in this note for further details

¹⁶⁴ 100-year GWP values specified for N₂O is 310 as per the IPCC Second Assessment Report, 1996, Technical Summary, Table 4. Available at https://www.ipcc.ch/ipccreports/sar/wg_1/ipcc_sar_wg_1_full_report.pdf

- Rural population = 773,814,531 persons¹⁶⁵
- Annual per capita protein consumption = 57 gm/person/year¹⁶³ × 365 days = 20.81 kg/person/year
- Fraction of Nitrogen in Protein (F_{NPR}) = 0.16
- Factor for Non-consumed protein added to the wastewater ($F_{NON-CON}$) = 1.40
- Factor for industrial and commercial co-discharged protein into the sewer system ($F_{IND-COM}$) = 1.25
- Nitrogen removed with sludge (N_{SLUDGE}) = 0

Total annual nitrogen in the wastewater effluent

$$= (773,814,531 \text{ persons} \times 20.81 \text{ kg/person/year} \times 0.16 \times 1.4 \times 1.25) - 0$$

$$= 4,507,779,170.45 \text{ kg N/Year}$$

Step 2: Calculation of N₂O emissions as per Equation 10

$$N_2O \text{ Emissions} = N_{EFFLUENT} \times EF_{EFFLUENT} \times 44/28$$

- Total annual amount of nitrogen in the wastewater effluent ($N_{EFFLUENT}$) = 4,507,779,170.45 kg N/Year
- Emission Factor for N₂O emissions from discharged to wastewater ($EF_{EFFLUENT}$) = 0.005 kg N₂O-N/kg N
- 44/28 - The factor is the conversion of kg N₂O-N into kg N₂O = 1.57

Total N₂O Emission from Domestic Wastewater (Rural) (tonnes of N₂O)

$$= (4,507,779,170.45 \text{ kg nitrogen} \times 0.005 \text{ N}_2\text{O-N/kg N} \times 1.57)/1000$$

$$= 35,418.26 \text{ tonnes of N}_2\text{O}$$

Total Emission from Domestic Wastewater (Rural) (tonnes of CO₂e)

= Emission in tonnes of N₂O × GWP of N₂O

$$= 35,418.26 \times 310^{164}$$

$$= 10,979,662.12 \text{ tonnes CO}_2\text{e}$$

Grand Total N₂O emissions from Domestic Wastewater at the National-level, year 2005

= Urban wastewater N₂O emission + Rural wastewater N₂O emission

$$= 4,576,230.41 + 10,979,662.12$$

$$= 15,555,892.54 \text{ tonnes of CO}_2\text{e}$$

6.2.3 Sample Emission Estimate Calculation for 4DI Industrial Wastewater Treatment and Discharge for Year 2007

Total CH₄ Emissions from Industrial Waste Water

$$CH_4 \text{ Emissions} = \sum_i (TOW_i - Si) EF_i - Ri \quad \text{-----Equation 12}$$

Where,

CH₄ Emissions = CH₄ emissions in inventory year, kg CH₄/yr

TOW_i = total organically degradable material in wastewater from industry i in inventory year, kg COD/yr

i = industrial sector

Si = organic component removed as sludge in inventory year, kg COD/yr

EF_i = emission factor for industry i, kg CH₄/kg COD for treatment/discharge pathway or system(s) used in inventory year

Ri = amount of CH₄ recovered in inventory year, kg CH₄/yr (default value of 0¹⁶⁶)

The equation for TOW in industrial wastewater is

$$TOW_i = P_i * W_i * COD_i \quad \text{----- Equation 13}$$

¹⁶⁵ Estimated based on urban population for year 2001 and annual growth rate of 1.23% calculated based on decadal growth rate from 2001-2011 as per Census of India data. Available at http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf

¹⁶⁶ As per 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6: Wastewater Treatment and Discharge and NEERI document on Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, 2010. Available at: <http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf>

Where,

TOW_i = total organically degradable material in wastewater for industry i, kg COD/yr

i = industrial sector

P_i = total industrial product for industrial sector i, t/yr

W_i = wastewater generated, m³ /t product

COD_i = chemical oxygen demand, kg COD/m³

Equation for CH₄ emission factor calculation for industry sector

$$EF_i = B_o * MCF_j \quad \text{----- Equation 14}$$

Where,

EF_j = emission factor for each treatment/discharge pathway or system, kg CH₄/kg COD

j = each treatment/discharge pathway or system

B_o = maximum CH₄ producing capacity, kg CH₄/kg COD

MCF_j = methane correction factor (fraction)

Step 1: Calculation of TOW as per Equation 13

$$TOW_i = P_i * W_i * COD_i$$

- P_i: Production for industry sector i (2007), tonnes¹⁶⁷
- W_i: Wastewater generated for industry sector i, m³/tonne product¹⁶⁸
- COD_i: Chemical oxygen demand for industry sector i¹⁶⁹, kg COD/m³

(a) Pulp & Paper

$$\begin{aligned} &= P_{\text{Pulp \& Paper}} \times W_{\text{Pulp \& Paper}} \times COD_{\text{Pulp \& Paper}} \\ &= 7,287,500.0 \text{ tonnes} \times 79.83 \text{ m}^3/\text{tonne} \times 5.90 \text{ kg COD/m}^3 \\ &= 3,432,408,393 \text{ kg COD/yr} \end{aligned}$$

(b) Fertilizer

$$\begin{aligned} &= P_{\text{Fertilizer}} \times W_{\text{Fertilizer}} \times COD_{\text{Fertilizer}} \\ &= 14,954,050 \text{ tonnes} \times 8 \text{ m}^3/\text{tonne} \times 3 \text{ kg COD/m}^3 \\ &= 358,897,200 \text{ kg COD/yr} \end{aligned}$$

(c) Sugar

$$\begin{aligned} &= P_{\text{Sugar}} \times W_{\text{Sugar}} \times COD_{\text{Sugar}} \\ &= 26,859,500 \text{ tonnes} \times 1 \text{ m}^3/\text{tonne} \times 2.50 \text{ kg COD/m}^3 \\ &= 67,148,750 \text{ kg COD/yr} \end{aligned}$$

(d) Coffee

$$\begin{aligned} &= P_{\text{Coffee}} \times W_{\text{Coffee}} \times COD_{\text{Coffee}} \\ &= 268,500 \text{ tonnes} \times 5 \text{ m}^3/\text{tonne} \times 9 \text{ kg COD/m}^3 \\ &= 12,082,500 \text{ kg COD/yr} \end{aligned}$$

(e) Dairy

$$\begin{aligned} &= P_{\text{Dairy}} \times W_{\text{Dairy}} \times COD_{\text{Dairy}} \\ &= 106,575,000 \text{ tonnes} \times 3 \text{ m}^3/\text{tonne} \times 2.24 \text{ kg COD/m}^3 \\ &= 716,184,000 \text{ kg COD/yr} \end{aligned}$$

(f) Beer

$$\begin{aligned} &= P_{\text{Beer}} \times W_{\text{Beer}} \times COD_{\text{Beer}} \\ &= 394,929.8 \text{ tonnes} \times 9 \text{ m}^3/\text{tonne} \times 2.90 \text{ kg COD/m}^3 \\ &= 10,307,666 \text{ kg COD/yr} \end{aligned}$$

(g) Meat

¹⁶⁷ Refer Table 41 for details of data sources for production data for all industry sectors

¹⁶⁸ Refer Table 42 for details of sources of this parameter for all industry sectors

¹⁶⁹ Refer Table 43 for details of sources of this parameter for all industry sectors

$$\begin{aligned}
 &= P_{i \text{ Meat}} \times W_{i \text{ Meat}} \times \text{COD}_{i \text{ Meat}} \\
 &= 3,581,750.0 \text{ tonnes} \times 11.70 \text{ m}^3/\text{tonne} \times 4.10 \text{ kg COD/m}^3 \\
 &= 171,816,548 \text{ kg COD/yr}
 \end{aligned}$$

(h) Soft drink

$$\begin{aligned}
 &= P_{i \text{ Soft drink}} \times W_{i \text{ Soft drink}} \times \text{COD}_{i \text{ Soft drink}} \\
 &= 771,719.0 \text{ tonnes} \times 3.70 \text{ m}^3/\text{tonne} \times 9 \text{ kg COD/m}^3 \\
 &= 25,698,243 \text{ kg COD/yr}
 \end{aligned}$$

(i) Tannery

$$\begin{aligned}
 &= P_{i \text{ Tannery}} \times W_{i \text{ Tannery}} \times \text{COD}_{i \text{ Tannery}} \\
 &= 510,600 \text{ tonnes} \times 32 \text{ m}^3/\text{tonne} \times 3.10 \text{ Kg COD/m}^3 \\
 &= 50,651,520 \text{ kg COD/yr}
 \end{aligned}$$

(j) Iron & Steel

$$\begin{aligned}
 &= P_{i \text{ Iron & Steel}} \times W_{i \text{ Iron & Steel}} \times \text{COD}_{i \text{ Iron & Steel}} \\
 &= 80,289,250 \text{ tonnes} \times 60 \text{ m}^3/\text{tonne} \times 0.55 \text{ kg COD/m}^3 \\
 &= 2,649,545,250 \text{ kg COD/yr}
 \end{aligned}$$

(k) Petroleum

$$\begin{aligned}
 &= P_{i \text{ Petroleum}} \times W_{i \text{ Petroleum}} \times \text{COD}_{i \text{ Petroleum}} \\
 &= 147,437,610 \text{ tonnes} \times 0.7 \text{ m}^3/\text{tonne} \times 1.0 \text{ kg COD/m}^3 \\
 &= 103,206,327 \text{ kg COD/yr}
 \end{aligned}$$

(l) Rubber

$$\begin{aligned}
 &= P_{i \text{ Rubber}} \times W_{i \text{ Rubber}} \times \text{COD}_{i \text{ Rubber}} \\
 &= 933,060 \text{ tonnes} \times 26.3 \text{ m}^3/\text{tonne} \times 6.12 \text{ Kg COD/m}^3 \\
 &= 150,181,525 \text{ kg COD/yr}
 \end{aligned}$$

Step 2: Calculation of CH₄ Emission Factors for Industry Sectors based on Treatment/Discharge Pathway as per Equation 14

Table 61: Calculation of the Industry-wise Methane Correction Factor

INDUSTRY ¹⁷⁰	Bo (KG CH ₄ /KG COD) ¹⁷¹	MCF ¹⁷²	EFi= Bo x MCF (KG CH ₄ /KG COD)
Iron & Steel	0.25	0	0
Fertilizer	0.25	0.2	0.05
Beer	0.25	0.8	0.2
Sugar	0.25	0.8	0.2
Soft Drink	0.25	0.8	0.2
Coffee	0.25	0.8	0.2
Petroleum Refineries	0.25	0	0
Dairy	0.25	0.8	0.2
Meat	0.25	0.8	0.2
Pulp & Paper	0.25	0.8	0.2
Rubber	0.25	0	0
Tannery	0.25	0.2	0.05

Step 3: Calculation of CH₄ Emission as per the Equation 12

$$\text{CH}_4 \text{ Emissions (tonnes)} = \sum_i ((TOW_i - S_i) \times EFi / 1000) - R_i$$

(a) Pulp & Paper

- TOW_i = 3,432,408,393 kg COD/yr

¹⁷⁰ Refer Table 44 in this note for further details on the prevalent treatment technology and corresponding MCF values

¹⁷¹ Bo value is taken as default value as per 2006 IPCC Guidelines, Vol. 5, Chapter 6.

Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

¹⁷² MCF value is taken based on treatment systems listed in 2006 IPCC Guidelines, Vol. 5, Chapter 6, Table 6.8 (see Table 40 in this note). Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

- $Si = 0.35 \text{ kg COD/yr}$
- $E_{Fi} = 0.20 \text{ kg CH}_4/\text{kg BOD}$
- $R_i = 0$

CH_4 Emissions (tonnes)

$$= ((TOW_i - Si) \times E_{Fi} / 1000) - R_i$$

$$= ((3,432,408,393 \text{ kg COD/yr} - 0.35 \text{ kg COD/yr}) \times 0.20 \text{ kg CH}_4/\text{kg BOD}) / 1000 - 0$$

$$= 686,481.68 \text{ tonnes CH}_4$$

(b) Fertilizer

- $TOW_i = 358,897,200 \text{ kg COD/yr}$
- $Si = 0.35 \text{ kg COD/yr}$
- $E_{Fi} = 0.20 \text{ kg CH}_4/\text{kg BOD}$
- $R_i = 0$

CH_4 Emissions (tonnes)

$$= ((TOW_i - Si) \times E_{Fi} / 1000) - R_i$$

$$= ((358,897,200 \text{ kg COD/yr} - 0.35 \text{ kg COD/yr}) \times 0.20 \text{ kg CH}_4/\text{kg BOD}) / 1000 - 0$$

$$= 17,944.86 \text{ tonnes CH}_4$$

(c) Sugar

- $TOW_i = 67,148,750 \text{ kg COD/yr}$
- $Si = 0.35 \text{ kg COD/yr}$
- $E_{Fi} = 0.20 \text{ kg CH}_4/\text{kg BOD}$
- $R_i = 70\%$

CH_4 Emissions (tonnes) (without methane recovery)

$$= (TOW_i - Si) \times E_{Fi} / 1000$$

$$= ((67,148,750 \text{ kg COD/yr} - 0.35 \text{ kg COD/yr}) \times 0.20 \text{ kg CH}_4/\text{kg BOD}) / 1000$$

$$= 13,429.75 \text{ tonnes CH}_4$$

CH_4 Emission (tonnes) (post Methane recovery)

$$= \text{CH}_4 \text{ emission (without methane recovery)} \times (1 - \text{Methane recovery fraction})$$

$$= 13,429.75 \times (1 - 0.70)$$

$$= 4,028.92 \text{ tonnes CH}_4$$

(d) Coffee

- $TOW_i = 12,082,500 \text{ kg COD/yr}$
- $Si = 0.35 \text{ kg COD/yr}$
- $E_{Fi} = 0.20 \text{ kg CH}_4/\text{kg BOD}$
- $R_i = 0\%$

CH_4 Emissions (tonnes)

$$= ((TOW_i - Si) \times E_{Fi} / 1000) - R_i$$

$$= ((12,082,500 \text{ kg COD/yr} - 0.35 \text{ kg COD/yr}) \times 0.20 \text{ kg CH}_4/\text{kg BOD}) / 1000 - 0$$

$$= 2,416.50 \text{ Tonnes CH}_4$$

(e) Dairy

- $TOW_i = 716,184,000 \text{ kg COD/yr}$
- $Si = 0.35 \text{ kg COD/yr}$
- $E_{Fi} = 0.20 \text{ kg CH}_4/\text{kg BOD}$
- $R_i = 75\%$

CH_4 Emissions (tonnes) (without methane recovery)

$$= (TOW_i - Si) \times E_{Fi} / 1000$$

$$= ((716,184,000 \text{ kg COD/yr} - 0.35 \text{ kg COD/yr}) \times 0.20 \text{ kg CH}_4/\text{kg BOD}) / 1000$$

$$= 143,236.80 \text{ tonnes CH}_4$$

CH₄ Emission (tonnes) (post Methane recovery)
 = CH₄ emission (without methane recovery) x (1 – Methane recovery fraction)
 = 143,236.80 x (1 – 0.75)
 = 35,809.20 tonnes CH₄

(f) Beer

- TOWi = 10,307,666 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH₄/kg BOD
- Ri = 75%

CH₄ Emissions (tonnes) (without methane recovery)
 = (TOWi – Si) x EFi / 1000
 = ((10,307,666 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH₄/kg BOD) / 1000 - 0
 = 2,061.53 tonnes CH₄

CH₄ Emission (tonnes) (post Methane recovery)
 = CH₄ emission (without methane recovery) x (1 – Methane recovery fraction)
 = 2,061.53 x (1 – 0.75)
 = 515.38 tonnes CH₄

(g) Meat

- TOWi = 171,816,548 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH₄/kg BOD
- Ri = 0

CH₄ Emissions (tonnes)
 = ((TOWi – Si) x EFi / 1000) - Ri
 = ((171,816,548 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH₄/kg BOD) / 1000 - 0
 = 34,363.31 tonnes CH₄

(h) Soft Drink

- TOWi = 25,698,243 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH₄/kg BOD
- Ri = 0

CH₄ Emissions (tonnes)
 = ((TOWi – Si) x EFi / 1000) - Ri
 = ((25,698,243 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH₄/kg BOD) / 1000 - 0
 = 5,139.65 tonnes CH₄

(i) Tannery

- TOWi = 50,651,520 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH₄/kg BOD
- Ri = 0

CH₄ Emissions (tonnes)
 = ((TOWi – Si) x EFi / 1000) - Ri
 = ((50,651,520 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH₄/kg BOD) / 1000 - 0
 = 2,532.58 tonnes CH₄

(j) Iron & Steel

- TOWi = 2,649,545,250 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0 kg CH₄/kg BOD

- $R_i = 0$

CH₄ Emissions (tonnes)

$$= ((TOW_i - S_i) \times EFi / 1000) - R_i$$

$$= ((2,649,545,250 \text{ kg COD/yr} - 0.35 \text{ kg COD/yr}) \times 0 \text{ kg CH}_4/\text{kg BOD}) / 1000 - 0$$

$$= 0 \text{ tonnes CH}_4$$

(k) Petroleum

- $TOW_i = 103,206,327 \text{ kg COD/yr}$
- $S_i = 0.35 \text{ kg COD/yr}$
- $EF_i = 0 \text{ CH}_4/\text{kg BOD}$
- $R_i = 0$

CH₄ Emissions (tonnes)

$$= ((TOW_i - S_i) \times EFi / 1000) - R_i$$

$$= ((103,206,327 \text{ kg COD/yr} - 0.35 \text{ kg COD/yr}) \times 0 \text{ kg CH}_4/\text{kg BOD}) / 1000 - 0$$

$$= 0 \text{ tonnes CH}_4$$

(l) Rubber

- $TOW_i = 150,181,525 \text{ kg COD/yr}$
- $S_i = 0.35 \text{ kg COD/yr}$
- $EF_i = 0 \text{ CH}_4/\text{kg BOD}$
- $R_i = 0$

CH₄ Emissions (tonnes)

$$= ((TOW_i - S_i) \times EFi / 1000) - R_i$$

$$= ((150,181,525 \text{ kg COD/yr} - 0.35 \text{ kg COD/yr}) \times 0 \text{ kg CH}_4/\text{kg BOD}) / 1000 - 0$$

$$= 0 \text{ tonnes CH}_4$$

Step 4: Total CH₄ emissions from industrial wastewater in tonnes of CO₂e

$$\text{CH}_4 \text{ Emission (tonnes CO}_2\text{e)} = \text{Emission in tonnes of CH}_4 \times \text{GWP of CH}_4^{173}$$

(a) Pulp & Paper

$$= 686,481.68 \times 21$$

$$= 14,416,115.25 \text{ tonnes CO}_2\text{e}$$

(b) Fertilizer

$$= 17,944.86 \times 21$$

$$= 376,842.06 \text{ tonnes CO}_2\text{e}$$

(c) Sugar

$$= 4,028.92 \times 21$$

$$= 84,607.42 \text{ tonnes CO}_2\text{e}$$

(d) Coffee

$$= 2,416.50 \times 21$$

$$= 50,746.50 \text{ tonnes CO}_2\text{e}$$

(e) Dairy

$$= 35,809.20 \times 21$$

$$= 751,993.20 \text{ tonnes CO}_2\text{e}$$

(f) Beer

$$= 515.38 \times 21$$

$$= 10,823.05 \text{ tonnes CO}_2\text{e}$$

¹⁷³ 100-year GWP values specified for CH₄ is 21 as per the IPCC Second Assessment Report, 1996, Technical Summary, Table 4. Available at https://www.ipcc.ch/ipccreports/sar/wg_1/ipcc_sar_wg_1_full_report.pdf

(g) Meat

$$= 34,363.31 \times 21$$

$$= 721,629.50 \text{ tonnes CO}_2\text{e}$$

(h) Soft Drink

$$= 5,139.65 \times 21$$

$$= 107,932.62 \text{ tonnes CO}_2\text{e}$$

(i) Tannery

$$= 2,532.58 \times 21$$

$$= 50,651,520 \text{ tonnes CO}_2\text{e}$$

(j) Iron & Steel

$$= 0 \times 21$$

$$= 0 \text{ tonnes CO}_2\text{e}$$

(k) Petroleum

$$= 0 \times 21$$

$$= 0 \text{ tonnes CO}_2\text{e}$$

(l) Rubber

$$= 0 \times 21$$

$$= 0 \text{ tonnes CO}_2\text{e}$$

Total CH₄ emissions from industrial wastewater in tonnes of CO₂e (2007)

= Sum of CH₄ emissions from all industrial sectors (i.e. Pulp & Paper + Fertilizer + Sugar + Coffee + Dairy + Beer + Meat + Soft Drink + Tannery + Iron & Steel + Petroleum + Rubber)

$$= 14,416,115.25 + 376,842.06 + 84,607.42 + 50,746.50 + 751,993.20 + 10,823.05 + 721,629.50 + 107,932.62 + 50,651,520 + 0 + 0 + 0$$

$$= 16,573,873.69 \text{ tonnes of CO}_2\text{e}$$