Sector: Waste

Sub Sector: Solid waste

GHG
Platform
INDIA

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Citation	Chaturvedula, S., Kolsepatil, N., Sangem, P., (2016). Waste Emissions. Version 1.0 dated July 15, 2016, from GHG platform India: GHG platform India-2007-2012 National Estimates - 2016 Series: http://ghgplatform-india.org/data-and-emissions/waste. html In instances where this sheet is used along with any other sector sheet on this website, the suggested citation is "GHG platform India 2007-2012 National Estimates - 2016 Series"
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Introduction

Solid waste generated is disposed in landfills, incinerated or open burnt. When solid waste is disposed in landfills and in the presence of anaerobic conditions, the methanogenic bacteria break-down the degradable organic component in the waste, releasing methane (CH_4) emissions. Decomposition of the organic content occurs slowly and the CH_4 emissions from a given mass of solid waste deposited continue to be released over a time period spanning a few decades.

This exercise provides a detailed estimation of the Green House Gas (GHG) emissions (in terms of CO_2 equivalent) from Solid Waste Disposal (IPCC code: 4A1) in the Waste sector in India.

The objective is to contribute towards establishment of the 'India GHG platform' – which aims to complement the national reporting process, as well as to drive an informed policy dialogue within the country on the industrial carbon emissions inventory and the possibility to reduce emissions in the decades ahead.

This document provides details on the adopted methodology, data sources, information gaps, and the GHG emission estimations for the time period from 2007 to 2012.

Scope of Assessment, Applicability and Boundary limitations:

In line with India's Second National Communication and the 2006 IPCC Guidelines for Waste, CH_4 emissions are estimated from disposal of solid waste in disposal sites in India. The assessment covers Municipal Solid waste (MSW), generally defined as waste collected by local municipal governments or other local authorities, typically including:

- Household waste
- Garden (yard) and park waste
- Commercial/institutional waste

Industrial waste and other waste such as clinical waste and hazardous waste are not are not considered in the analysis, in consonance with India's Second National Communication. The reporting period considered is from 2007 to 2012.

Rural areas are largely lacking in requisite systems for solid waste management and its scientific disposal in landfill sites. Thus a majority of solid waste in rural areas does not decompose under controlled/semi-controlled anaerobic conditions and thereby does not contribute to any significant CH_4 emissions. Thus in line with India's Second National Communication, only disposal of solid waste in urban areas is considered in the assessment.

The First Order Decay (FOD) model which estimates emissions from decomposition of solid waste in waste disposal sites over a period of time, as per the 2006 IPCC guidelines, is used for 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 CH_4 over a subsequent period of time. CH_4 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 CH_4 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 CH_4 from this specific amount of waste decreases gradually. As per the model and India's Second National Communication, it is assumed that a period of 50 years is appropriate for CH_4 emissions from a given quantum of waste to come down to significant level. Thus in this assessment, the waste disposal and resultant emissions are estimated over a period of 50 years prior to 2007 i.e. 1956-2006.

Prevalent waste management practices such as open dumping/unmanaged landfill, waste characteristics and composition, per capita waste generation rates over the years in Indian cities are also factored in the methodology and emission estimation.

Methodology

The potential CH_4 emission that is generated as a result of the degradation of organic material under anaerobic conditions throughout the years can be estimated on the basis of the amounts and composition of the waste disposed into Solid Waste Disposal Sites (SWDS) and the waste management practices at the disposal sites.

As per the 2006 IPCC Guidelines and India's Second National Communication, the following equations are used to estimate CH_4 emission from Solid waste disposal:

CH_4 EMISSION FROM SWDS

$$CH4\ Emissions = [\sum CH_4\ generatedT - R_T] * (1 - OXT)$$

Where,
CH_4 Emissions = CH_4 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 0[1])
OX_T = oxidation factor in year T, (fraction) (default value of 0[1])

The amount of CH_4 formed from decomposable material is found by multiplying the CH_4 fraction in generated landfill gas and the CH_4/C molecular weight ratio (16/12).

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

CH_4 GENERATED FROM DECAYED DDOCm

$$CH4\ generatedT = DDOC_{mdecompT} * F * 16/12$$

Where,
CH_4 generatedT = amount of CH_4 generated from decomposable material
DDOCm decompT = DDOCm decomposed in year T, Gg
F = fraction of CH_4, by volume, in generated landfill gas (fraction) (default value of 0.5[1])
16/12 = molecular weight ratio CH_4/C (ratio)

The basis for the calculation is the amount of Decomposable Degradable Organic Carbon (DDOCm). DDOCm 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 in the waste (DOC), the fraction of the degradable organic carbon that decomposes under anaerobic conditions (DOCf), 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 DATA

$$DDOC_{m} = W * DOC * DOCf * MCF$$

Where,
DDOCm = 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
DOCf = fraction of DOC that can decompose (fraction) (Default value of 0.5[1])
MCF = CH_4 correction factor for aerobic decomposition in the year of deposition (fraction) (default value of 0.4[1])

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:

ESTIMATES DOC USING DEFAULT CARBON CONTENT VALUES

$$DOC = \sum_{i} (\mathrm{DOCi} * \mathrm{Wi})$$

Where,
DOC = fraction of degradable organic carbon in bulk waste, Gg C/Gg waste
DOCi = fraction of degradable organic carbon in waste type i
Wi = fraction of waste type i by waste category

The default DOC values for various fractions in MSW are given in Table 1. Since Plastics, Glass and Metals don't contain degradable organic carbon they have DOC value as zero.

Table 1: Default DOC content of different MSW components

MSW component	DOC content in % of wet waste	DOC content in % 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, Chapter 3 – Solid Waste disposal)

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 SWDS is irrelevant to the amount of CH_4 generated each year. It is only the total mass of decomposing material currently in the site that matters. This also means that when we know the amount of decomposing material in the solid waste disposal site at the start of the year

DDOCm ACCUMULATED IN THE SWDS AT THE END OF YEAR T

$$DDOCmaT = DDOCmdT + (DDOCmaT - 1 * e^{-k})$$

DDOCm DECOMPOSED AT THE END OF YEAR T

$$DDOCmdecompT = DDOCmaT - 1 * (1 - e^{-k})$$

Where,

T = inventory year
DDOCmaT = DDOCm accumulated in the SWDS at the end of year T, Gg
DDOCmaT-1 = DDOCm accumulated in the SWDS at the end of year (T-1), Gg
DDOCmdT = DDOCm deposited into the SWDS in year T, Gg
DDOCm decompT = DDOCm decomposed in the SWDS in year T, Gg
k = reaction constant, k = ln(2)/t1/2 (y-1) = 0.17 as per IPCC Guidelines
t1/2 = half-life time (y)

Data Sources and Assumptions

1. Human Population

The urban population of India is estimated on the basis of population data and decadal population trends for the preceding 50 year time period between 1956-2006 and for the emission reporting period of 2007-2012 as per the National Census[2].

[2] Census India : http://censusindia.gov.in/Census_Data_2001/India_at_glance/variation.aspx

2. Mass of Waste deposited (W)

The FOD method assumes that carbon in waste decays gradually to produce CH_4 emission. As per India's Second National Communication, it is assumed that in 50 years, CH_4 emission comes down to insignificant level. Hence, it is necessary to estimate or collect 50-year data on waste disposal prior to 2007 i.e. from 1956-2006.

Since time series waste disposal data for the last 50 years data is not available, 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 2007 as shown in Table 2. These annual growth rates are consistent with other studies which indicate a growth rates of 1%-1.33% per annum indicated in other studies for this time period[3].

Table 2: Decadal daily Per capita Waste generation and Annual growth rates

Year	Daily Per capita Waste generation (gm/day)[4]	Annual Per capita Waste generation (kg/annum)	Annual Growth rate[5]
1951	305	111.33	1.1%
1961	340	124.10	1.0%
1971	375	136.88	1.5%
1981	430	156.95	0.7%
1991	460	167.90	1.2%
2007	550[6]	200.75	1.2%[7]

As per India's Second National Communication, it is it is assumed that only 70% out of the total waste generated reaches the disposal sites and CH_4 emissions resulting from its decomposition under anaerobic conditions are estimated.

3. Degradable Organic carbon (DOC)

This is a key input in the calculation of emissions from MSW using the FOD model. The DOC value depends on the composition of waste.

The default value for DOC as per the 2006 IPCC Guidelines and as indicated in India's Second National Communication is 0.11. However, this aggregate DOC value based on an assumed composition of solid waste in India.

[3] K. J. Nath(1984): 'Metropolitan solid waste management in India' indicates an annual growth rate of 1% in per capita waste generation for pre-1980; Planning Commission (1995): 'Report of the High Power Committee on Urban Solid Waste management in India' indicates an annual growth rate of 1.33% in per capita waste generation for post 1990

[4] TERI (1998): Looking Back to Think Ahead: Green India 2047'

[5] Annual Growth rates have been estimated based on per capita generation rates available for years as given in the Table and used to estimate per capita generation rates for the intervening years.

[6] Based on India's Second National Communication to the United Nations Framework Convention on Climate Change

[7] The annual growth rate of 1.2% estimated based on data for 1991 and 2007 has been used to estimate per capita generation rates from 2008-2012.

The composition of waste is changing with lifestyles and this is also seen from waste composition data available for three different years (1971, 1995 and 2005) from studies conducted by the Central Pollution Control Board (CPCB) and the National Environmental Engineering Research Institute (NEERI). 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 all the 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. 1956-1994, 1995-2004 and 2005-2012 (see Table 3). Using the default values for DOC content (see Table 1) for the degradable fractions in waste[8], the DOC values for the organic portion of the waste are calculated for the time periods 1956-1994, 1995-2004 and 2005-2012 as shown in Table 3.

Table 3: Estimated Degradable Organic Content using Waste Composition

Component	**Waste Composition**			**Default DOC Content values (Wet waste) in % from Table 1 as per 2006 IPCC Guidelines**
	1971[9]	**1995[9]**	**2005[10]**	
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	**1956-1994**	**1995-2004**	**2005-2012**	**-**

(Source: CPCB and NEERI, CPHEEO)

4. DDOCm decomposed in year T (DDOCm $_{decompT}$)

The DDOCm (i.e. the Decomposable Degradable Organic Carbon) decomposed in the year T (DDOCm $_{decompT}$) depends on the DDOCm deposited in the year T (DDOCmdT), the DDOCm accumulated at the end of year T (DDOCmaT) and DDOCm accumulated at the end of the previous year (T-1) (DDOCmaT-1) (see equation for DDOCmdecompT in Methodology section). It is assumed the DDOCm accumulated in the initial year of the 50 year time period considered under the FOD model (i.e. 1956) is zero.

Using the values estimated for DDOCm deposited and DDOCm accumulated, the DDOCm decomposed is calculated for all the 50 year time period from 1956-2006 and subsequently is used to estimate CH_4 emissions from 2007-2012.

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[8] Other inorganic or non-degradable fractions such as plastics, glass, metals, rubber, ash and fine earth, inert material are not considered since these will not have degradable organic content and thus will not lead to any CH_4 emissions from decomposition

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

[10] The Central Public Health and Environmental Engineering Organisation (CPHEEO), Ministry of Urban Development, GoI (2015): Manual on Municipal Solid Waste Management-2015

Results and Comparison with National Inventory

The GHG emission estimates for time period 2007-2012 along with a comparison with official national reporting (for years 2007 and 2010) are given in Table 4. The estimates for 2007 and 2010 show an under-estimation, with a deviation of 12.5% and 7.14% as compared to the national reporting estimates.

Table 4: Results of GHG emission Estimation and Comparison with National Inventory Reporting

GHG Emissions from Solid Waste Disposal (Megatonnes of CO_2e)	2007	2008	2009	2010	2011	2012
India GHG Platform Estimates	10.76	11.47	12.16	12.85	13.52	14.18
As per Second National Communication (2007) and Biennial Update Report (2010)	12.69	-	-	13.96	-	-
Deviation as compared to official estimates (%)	-15.21%	-	-	-7.95%	-	-

The possible reasons for the deviation from official estimates are discussed below:

- To accurately account for accumulated DOC and potential CH_4 generation from historic waste disposal, the FOD model suggests that emission estimations be done for a 50 year period preceding the inventory year. 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 Communication for 2007 indicates a value of 0.55 kg/day/capita for the average per capita waste generation rate. The Second National Communication and the Biennial Update Report 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 nationally acceptable secondary sources for one year in each of the five decades (1951-2007) (see Table 2) have been used to calculate the waste generation over the time 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.
- The Urban population used to calculate the total waste generated and disposed in the emission estimation reporting period between 2007 to 2012 and for the fifty years preceding 2007 is based on population data, decadal trends and decadal growth rates as per the National Census. The Second National Communication and the Biennial Update Report do not provide details of the urban population that is used for the estimations. Possible variation in the methods used to arrive at urban population can be a likely source of deviation.
- The default value for DOC as per the 2006 IPCC Guidelines and used to calculate emissions in India's Second National Communication for 2007 is 0.11 which 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 as a result of changing lifestyles. 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 using the default DOC content from IPCC (see Table 1) for the constituent degradable fractions based on the changing waste composition over the three time periods of 1956-1994, 1995-2004 and 2005-2012.

- CH_4 emission estimates done by assuming a constant DOC value of 0.11 across the period of assessment (as per the Second National Communication) results in CH_4 emission of 11.78 Megatonnes of CO_2e and 13.22 Megatonnes of CO_2e for year 2007 and 2010 respectively, which is relatively closer to the official emission estimates as per Second National Communication and the Biennial Update Report. The variation of this estimate with respect to the final estimates prepared under our assessment (by considering different DOC values over three time periods) is 9.45% and 2.89% respectively. However due to the reasons indicated above, our assessment factors in changing waste composition and uses varying values of DOC over time in the final emission estimates.

Remarks

Limited clarity and information is provided in the National Communication Reports and the Biennial Update Report on values, assumptions and data sources for parameters such as Urban population, per capita waste generation, degradable organic content and accumulated degradable organic content in the preparation of the 2007 and 2010 national inventories. Details of the assumptions and disaggregated results of GHG emission for Solid waste are not available in these documents as well.

Limited updated information on country specific values for parameters such as MSW composition, Degradable organic content and per capita waste generation rates, extent of waste generated that is going to disposal sites in the IPCC guideline documents and also in other secondary sources to enable an accurate and updated estimation of GHG emissions from Solid waste disposal.

Improved transparency with regards to availability of the underlying datasets and assumptions used for the official National GHG emission estimates in the public domain will greatly help in improving the accuracy of this assessment, enable better comparability, and help identify and address any limitations in the estimates done under this assessment as well as official emission estimates.