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Greenhouse Gas Emissions and Reduction Stratagems from Waste Sector in India

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Abstract: India's population growth, urbanization trends, patterns of income distribution, and increasing industrial production leads to increasing waste generation. Inappropriate waste management results in emission of greenhouse gases (GHG) constituting methane and nitrous oxide, contributing to global warming. IPCC 2006 model estimated GHG emissions from waste sector across India considering a gross domestic product growth rate of 6.5 percent as 70.13 million tones CO_2 eq in the year 2011, expected to rise 1.60 times by the year 2031. Emission mitigation options for waste sectors including diversion of organic waste from landfills towards treatment options, diversion of wastewater from domestic and commercial sectors towards sewer, and further capturing and utilising methane from landfills and effluent treatment units indicate a potential to lower the emissions to around 78.75 million tonnes CO_2 eq in year 2031. There is an urgent need to apply appropriate policy, political will, financial resources, capacity building, and indigenous technology to reduce impact of our activities on global warming. This paper has substantial implications for strategy makers and technocrats in formulating policies to reduce global warming.

Keywords: Global Warming, Greenhouse Gases, Solid Waste Management, Policies, Wastewater,

1. Introduction

Unmanaged landfill sites and inefficient wastewater treatments, without methane recovery, are the key sources to contribute to greenhouse gas (GHG) emissions from waste. The Central Pollution Control Board, Government of India, reported that municipal areas in India generate 1,35,198 tonnes per day (TPD) of Municipal Solid Waste (MSW); 82.12 per cent generated waste is collected and of this 76.96 per cent collected waste remains untreated[1]. Hence, the MSW, put in low lying urban areas is an enormous 1,09,626 TPD, including uncollected and collected but untreated wastes, which requires 2,16,203 $m^3 d^{-1}$ volume and about 788 x 10^4 m^2 of precious land area per year. Efficient technologies for MSW management reduce the waste management cost through recovery and reuse, enabling to keep cities cleaner and free from pollution. There are at present 13 identified landfill sites with methane capture potential in the country [2].

There is a huge gap between wastewater generation, treatment, and discharge in urban areas, a major fraction of the wastewater discharged is not even collected and a large fraction of the collected wastewater is in fact disposed untreated. Domestic and commercial establishments discharge wastewater, treated through different treatment pathways without aiming to reduce GHG emissions. Industrial wastewaters are also being treated without aiming for GHG reduction and there has only been some amount of methane recovery through sugar, beer, distillery, and dairy industries and a need to capture methane from pulp & paper and other potential industries, with high efficiency through enclosed flaring systems, has emerged.

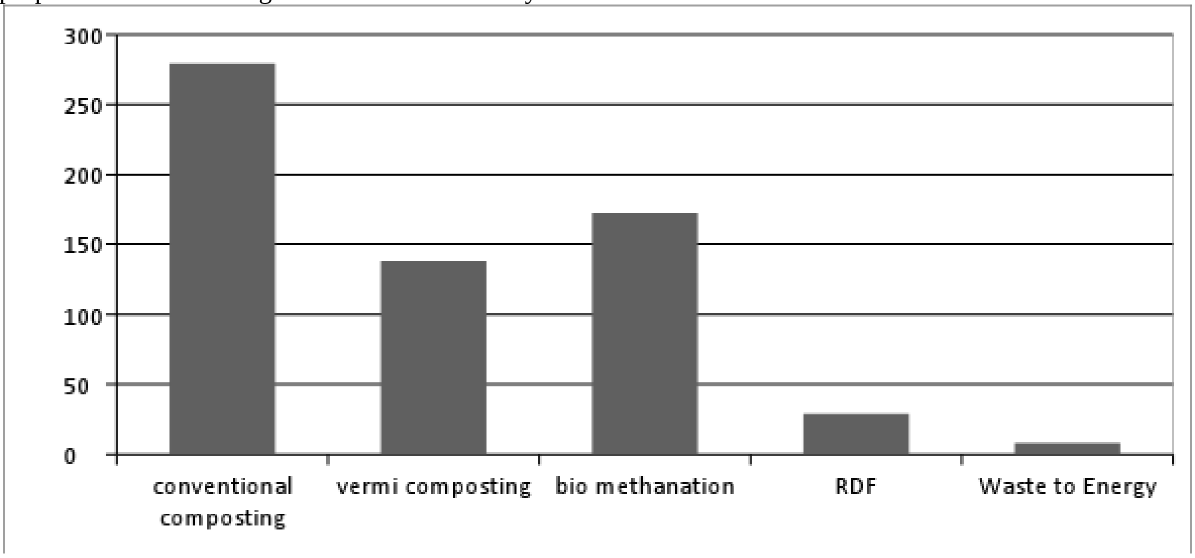
The waste generation pattern is related to the changing lifestyle and growing urban population. Table 1 shows the MSW generation rates in various cities of India.

Table 1 Solid Waste Generation by CPCB in 2004–05

City	Generation rate
Greater Mumbai	0.45 kg $c^{-1}d^{-1}$
Delhi	0.57 kg $c^{-1}d^{-1}$
Kolkata	0.58 kg $c^{-1}d^{-1}$
Chennai	0.62 kg $c^{-1}d^{-1}$

Source: [3]

Among the 59 cities surveyed by CPCB, MSW generated has about 52.40 per cent degradable fraction. Lack of public awareness and apathy towards the seriousness to deal with the issue are the major barriers in proper solid waste management across the country.



Source: [4]

The various treatment options existing in various parts of the country have been illustrated in Fig 1. Treatment options such as waste incineration, conversion to refuse derived fuel (RDF), composting, and biomethanation are being explored for tackling the increasing municipal solid waste in India. Volume reductions by incineration of waste may be in tune of 75 to 95 % [5]. However, there are disadvantages like emission of carcinogenic dioxins and other pollutants that arise from the stacks of the incinerator. Nevertheless, if appropriately treated, they can be reduced commendably. Similarly, The minimum waste quantity required for setting a RDF-based power plant has been reported as 500 TPD and so waste-to-energy plants may be set up in larger cities. The smaller cities may produce RDF which will be feeding the large waste to energy plants [6]. However, there are no guidelines for reducing the methane emissions from waste sector till date.

Regarding wastewaters, metro cities, class I cities, and class II towns in India generate about 62,000 MLD of wastewater and effectively treat only 30.45% (18,883 MLD). As of March 2015, about 1,237.16 MLD of installed capacity remained un-operational and the capacity of 2,528.36 MLD was under construction stage. Additionally, 628.64 MLD of treatment capacity continues to remain in proposed stages [7]. Ample percentage of wastewater which remains uncollected goes directly to the ecosystem where the degradation occurs under aerobic conditions. The wastewater collected enters various treatment pathways and is subjected to treatment, based on aerobic or anaerobic processes. Anaerobic treatment yields methane, if the quantity of methane generated is small, flaring of methane to convert it to carbon dioxide is considered. Further, the undigested proteins that become part of domestic wastewater streams also yield nitrous oxide during denitrification.

In India, about one-fourth of the treatment technologies used for Domestic wastewater are anaerobic, discharging 0.6kg CH_4/kg BOD [8]. Untreated wastewater sludge leads to generation of methane rich gas which is a source of GHG. India also extensively uses primary treatment systems such as communal septic tanks and low cost secondary treatment systems such as stabilization ponds. On the industrial side, wastewater from dairy, beer, textile, meat, fertilizer, sugar, coffee, soft drink, pulp & paper, petroleum, rubber, iron & steel and tannery industries contribute to substantial percentage of GHG emission when the wastewaters are treated through various treatment systems. Both methane and nitrous oxide are GHG and there is no policy targeting to reduce these emissions.

Ministry of environment, forests and climate change had communicated to United Nations framework convention on climate change (UNFCCC) its emissions in year 1994, 2000, 2007 and 2010. Yet no study was conducted to project the emissions by Indian economy in future and the ways in which these can be reduced. This paper uses the developed IPCC 2006 model to predict methane emissions till year 2031 based on baseline scenario and finds out alternate ways which can help reduce the methane emissions.

The objective of this paper is to access the reduction on GHG emissions from waste sector in India by:

a. Diverting organic solid waste through various treatment process technologies,

b. Implementing various levels of sewage treatment and recovering methane from domestic and commercial wastewaters, and
c. Implementing methane recovery in pulp & paper industries and increase in methane recovery in other industries.

2. Materials and Methods

2.1 Solid waste sector

The methane generation from waste has been estimated using 2006 IPCC guidelines for national GHG inventories [9]. The GHG emissions are attributed from solid waste landfills in the form of methane and steps followed for estimation of GHG emissions from solid waste are as follows(Eqs. (1-5)):

Step 1:

$$DDOC_m = W \times DOC \times DOC_f \times MCF \quad (1)$$

Where,

$DDOC_m$	Amount of decomposable degradable organic cabon deposited, Gg
W	Mass of waste deposited, Gg
DOC	fraction of degradable organic carbon in the year of deposition
DOC_f	Degradable organic carbon that decomposes under anaerobic conditions
MCF	Methane correction factor

Step 2:

$$DDOC_{mat} = DDOC_{mdt} + \left(DDOC_{mat-1} \times e^{-k}\right) \quad (2)$$

Where,

$DDOC_{mat}$	$DDOC_m$ accumulated in SWD at end of year t
$DDOC_{mat-1}$	$DDOC_m$ accumulated in SWD at end of year $t-1$
$DDOC_{mdt}$	$DDOC$ deposited into SWDS in year t
t	Inventory year
k	Reaction constant $\frac{ln(2)}{t_{\frac{1}{2}}}$ in per year (default value 0.17)

Step 3:

$$DDOC_{mdecomp\,t} = DDOC_{mat-1} \times \left(1 - e^{-k}\right) \quad (3)$$

Where,

$DDOC_{mdecomp\,t}$ $DDOC$ decomposed into SWD in year t

Step 4:

$$CH_4 generation\ potential\ (L_o) = DDOC_{mdecom\,t} \times F \times \frac{16}{12} \quad (4)$$

Where,

F Fraction of CH_4 generated in landfill gas

Step 5:

$$CH_4 generated\ \left(\frac{Gg}{Yr}\right) = \left[\sum_x L_o - R_t\right] \times \left(1 - OX_t\right) \quad (5)$$

Where,

OX_t	Oxidised methane in year t (default value as zero)
R_t	Recovered methane in year t (default value as zero)
t	Inventory Year
x	Waste category/type of material

The amount of solid waste generated as 0.55 kg c^{-1} d^{-1} for urban population, with 70% of the waste going to the solid waste disposal landfills, 20% to treatment facilities for composting, and the remaining 10% towards other unspecified streams. Further, the GHG emissions have been estimated using First Order Decay (FOD) method. Degradable organic carbon that decomposes under anaerobic conditions are taken as 50%, 0.4 as methane correction factor for uncategorized solid waste disposal sites as the default values and average degradable organic content fraction as 0.11.

2.2 Domestic and commercial wastewaters

The steps followed for estimation of methane emissions from domestic wastewater treatment are (Eqs(6-8)):

Step 1:

$$EF_j = B_o \times MCF_j \quad (6)$$

Where,

EF_j	Emission Factor kg $\frac{CH_4}{kgBOD}$
B_o	Max CH_4 producing potential, kg CH_4 per kg BOD (default value 0.6)

MCF	Methane correction factor

Step 2:

$$TOW = P \times BOD \times 0.001 \times I \times 365 \quad (7)$$

Where,

P	Population in inventory year (persons)
BOD	Per capita BOD in inventory year, g/c/d
I	Correction factor for industrial BOD into sewers

Step 3:

$$CH_4 Emission = [\textstyle\sum_{i,j} U_i \times T_{ij} \times EF_i] \times (TOW - S) - R \quad (8)$$

Where,

CH_4	Emissions CH_4 emissions in inventory year, kg CH_4/year
U_i	Fraction of population in income group i in the 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 low and urban high.
j	Each treatment/ discharge pathway or system (sewer, septic tank, latrine, other, and none)
EF_i	Emission factor, kg CH_4 / KG BOD
TOW	Total organic load in wastewater in inventory year, kg BOD/yr
S	Organic component removed as sludge in the inventory year, kg BOD/year
R	Amount of CH_4 recovered in the inventory year, kg CH_4/year

The values of MFC, B_o for different treatment pathways are provided in Table 2 along with estimated value of $EF_{j.}$

Table 2: Emission Factor From Various Treatment Pathways

Parameters	Domestic	Septic Tank	Latrine	Sewer	Other	None
MCF	0.5	0.1	0.1	0.1	0.0	0.0
B_o	0.6	0.6	0.6	0.6	0.6	0.6
EF_j	0.30	0.06	0.06	0.06	0.00	0.00

For this analysis, the population has been desegregated into three income groups—rural, urban low, and urban high. Table 3 describes the degree of utilization of different pathways by various income groups.

Table 3: Degree of Utilization Of Treatment Pathway/Method For Each Income Group (Tij)

Group	Domestic	Septic Tank	Latrine	Sewer	Other	None
Rural	-	-	0.47	0.10	0.10	0.33
Urban high	-	0.18	0.08	0.67	0.07	-
Urban low	-	0.14	0.10	0.53	0.03	0.20

-Negligible

Source: [9]

Total organics in wastewater is considered as 34g of BOD c^{-1} d^{-1} with a multiplication factor of 1.25 for capturing additional industrial BOD discharged into sewers. Organic component removed as sludge in the reference scenario is assumed to be zero and the amount of methane recovered in the reference scenario is also assumed as zero.

2.2.1 Nitrous Oxide Emissions

Nitrous oxide (N_2O) 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. Direct emissions from nitrification and de-nitrification at wastewater treatment plants may be considered as a minor source.

The steps followed in estimation of nitrous oxide emissions from domestic wastewater are(Eqs(9-10)):

Step 1:

$$N_{effluent} = P \times protien \times F_{npr} \times F_{non-con} \times F_{ind-com} - N_{sludge} \quad (9)$$

Where,

P	Population for the year
$Protien$	Annual per capita protein consumption in kg/p/yr
F_{npr}	Fraction of nitrogen in protein, kgN /kg protein
$F_{non-con}$	Factor for non-consumed protein added to wastewater
$F_{ind-com}$	Factor for industrial & commercial co discharged protein into sewer system
N_{sludge}	Nitrogen removed from sludge, kg N/yr

Step 2:

$$N_2O_{emission} = N_{effluent} \times EF_{effluent} \times \frac{44}{28} \quad (10)$$

Where,

$N_2O_{emission}$	N_2O emissions in inventory year in kg N_2O/yr
$N_{effluent}$	Nitrogen in effluent discharged to aquatic environment kg N/yr
$EF_{effluent}$	Emission factor (0.0005 - 0.25) kg N_2O/kgN

Here the per capita protein consumption has been considered as the basis for calculating nitrous oxide emissions from wastewater. The annual per capita protein consumption has been taken as 25.97 kg c^{-1} y^{-1} in 2011 and around 27.95 kg c^{-1} y^{-1} in 2025 and 28.62 kg c^{-1} y^{-1} in 2031, looking into the food security and supply trends of the country as assessed by WHO [11]. Considering a fraction of nitrogen in protein as 0.16 kg N per kg protein along with correction factor of 1.1 and 1.25 for unutilized, protein and co discharge from commercial and industrial establishments respectively, the nitrogen available in wastewaters has been estimated. Nitrogen in sludge removed is considered as zero. The emission factor of N_2O kg per kgN has been used as 0.005 [9].

2.3 Industrial Wastewater Treatment

Methane emissions from wastewater treatment of various industries such as iron and steel, rubber, beer, meat, coffee, soft drinks, petroleum refineries, pulp and paper, sugar, tannery, fertilizer and dairy industries have been estimated.

The steps used to estimate the methane emissions from wastewater treatment are as follows(Eqs(11-13)):

Step 1:

$$TOW_i = P_i \times W_i \times COD_i \quad (11)$$

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, m^3/t product
COD_i	Chemical oxygen demand load, kg COD/m^3

Step 2:

$$EF_i = B_o \times MCF_j \quad (12)$$

Where,

EF_i	Emission factor for each treatment/discharge pathway or system, kg CH_4/kg COD,
j	Each treatment/discharge pathway or system
B_o	Maximum CH_4 producing capacity, kg CH_4/kg COD
MCF_j	Methane correction factor (fraction)

Step 3:

$$CH_4 emission = \sum_i [[TOW_i - S_i] \times EF_i - R_i] \quad (13)$$

Where,

CH_4	Emissions methane emissions in inventory year, kg CH_4/yr
TOW	Total organically degradable material in wastewater from industry I in inventory year kg COD/year
i	Industrial sector
S_i	Organic component removed as sludge in inventory year, Kg COD /yr
EF_i	Emission factor for industry i, kg CH_4/kg COD for treatment pathway used in inventory year. If more than one treatment practice is used in an industry, this factor would need to be a weighted average.

R_i Amount of CH_4 recovered in inventory year, kg CH_4/yr

Table 4 presents the values of wastewater generated per tonne of various industrial products used in the analysis.

Table 4: Wastewater Generated from Various Industrial Products In India

Industry	Wastewater generation (m^3 $tonne^{-1}$)	COD (kg m^{-3})
Iron and Steel[1]	60.0	4.62
Fertilizers[1]	8.0	1.83
Beer	6.3	2.90
Dairy	7.0	2.70
Meat	13.0	4.10
Sugar	11.0	3.20
Coffee[1]	5.0	9.00
Soft drink[1]	3.7	3.41
Pulp and paper	162.0	5.70
Petroleum	0.6	1.00
Rubber[1]	26.3	8.00
Tannery	35.0	5.00

Source: [1][8] [9]

Recovery of methane by sugar, beer and dairy industries have been considered as 70%, 75% and 75% respectively. Methane recovery for other industrial sectors has been considered as negligible in reference scenario.

3. Results and Discussions

3.1 GHG Emissions from Reference Scenario

Reference Scenario (RES) depicts a baseline showing the nation's GHG emissions from waste sector, assuming no mitigation measures are adopted. Taking account of existing policy commitments and assuming that those recently announced are implemented; whenever necessary, a diversion from Government projections/forecasts has also been assumed. The compounded annual growth rate (CAGR) of GHG emissions from solid waste from 2011 to 2031 is 2.55% with respect to GHG emission of 13.75 million tonnes CO_2 eq in 2011.

With 112.33 million tonnes of CO_2 eq GHG emissions in 2031 from waste sector, the total GHG emissions are projected to increase at a CAGR of 2.38% from 2011 to 2031. The highest growth rate is seen in industrial wastewater with 2.68% from 2011 to 2031. For domestic and commercial wastewater, the CAGR is 1.73% from 2011 to 2031. The CO_2 eq share in 2006 had been 48.48% from industrial wastewater, 31.64% from domestic and commercial wastewater, and 19.88% from solid waste sector. The industrial wastewater treatments are projected to contribute the highest share of 53.23% among waste sector GHG emissions in 2031 followed by 26.50% from solid waste sector and 20.27% from domestic and commercial wastewater.

3.2 GHG Mitigation Options

Under municipal solid waste there is a need for a great emphasis on the 4Rs with defined strategies; the first emphasis is on waste reduction, thereafter, reusing the discarded materials by one process into the other. Once the materials are out of the loop and cannot be further reused, the waste can be treated and recycled back in another form to be reused as a raw material for other use. Once the material is out of this loop, it shall be non reusable and can be used to recover energy in the form of heat or other high calorific value products. Lastly, the ashes and other inert substances with no recoverable value are disposed in sanitary landfill.

Studies have reported that there are 13 landfill sites in India with potential for LFG recovery [2] These LFG recovery sites are an option for reducing GHG emissions arising from deposition and decomposition of waste. The Municipal Solid Waste Rules for 2000 and 2016 stipulate that no organic waste shall be sent to landfills, so in future there will be no scope for landfill gas generation on the newer landfill sites. As per the recent study done the percentage of methane in LFG from sites in India varied between 30 to 50% and this low-grade fuel can be flared or offered for co-generation pathways for reducing methane emissions from the sites [11].

Table 5: Identified Landfill Sites with Methane Reduction Potential

Landfill	Starting year	Quantity of MSW disposed (tonnes) (till year)	Designed capacity (million tonnes)	LFG recovery (m^3/hr)
Uruli Devanchi, Pune	1999	2.9 (2009)	3.2	400
Autonagar landfill, Hyderabad	1984	1.2 (2005)	1.2	42
Gorai Landfill, Mumbai	1972	2.5 (2007)	2.8	684
Balsawa Landfill, Delhi	1992	6.9 (2008)	8.0	2400
Pirana Landfill, Ahmedabad	1985	4.6 (2008)	4.6	1300
Deonar Landfill, Mumbai	1927	12.6 (2008)	12.7	2200
Dhapa, Kolkata	1981	7.0 (2009)	14.8	3200
Shadara Landfill, Agra	1979	4.7 (2009)	0.5	97
Barikalan Dubagga	1994	2.9 (2007)	0.4	36
Moti Jheel Landfill, Lucknow	1972	2.9 (1998)	0.3	11.5
Okhla Landfill, New Delhi	1994	6.8 (2009)	7.7	1660
Ghazipur Landfill, Delhi	1984	11 (2008)	1.9	1200
Kuruvadikuppam Landfill, Punducherry	2003	0.6	-	22.8

Source: [2]

Under domestic and commercial wastewater, sludge generated through the wastewater treatment plants which are a potential source of methane generation shall have to be digested in anaerobic digesters and the methane generated thereof shall be flared or used for cooking or can be even reused in cogeneration plants and boilers.

Industrial Wastewater

Pulp and paper industry accounts for about 75% of the GHG emissions from the industrial sector. Use of anaerobic digesters with methane capture and reuse or flaring is one of the prominent mitigation options. The methane captured can be utilized to generate electricity or used as a fuel in boilers. The methane capture and reuse in industries like brewery, dairy, and sugar also needs to be more efficient.

3.2.1 Mitigation Option 1(moderate)

Determined effort for diversion of organic waste: 20% diversion in 2021 and 40% in 2031 along with LFG recovery. This organic fraction of the MSW shall be diverted to composting, biomethanation, and RDF facilities. For LFG recovery, two landfill sites Dhapa (Kolkata) and Ghazipur (Delhi) are assumed to be capturing landfill gas and will reduce about 9.91 Gg CH_4 in 2021, further; the Gorai landfill in Mumbai will also reduce about 8.99 Gg CH_4 in 2026 with LFG capture. With reduction in organic waste going to landfills, there shall be no landfill gas potential post-2028 except, Dhapa landfill at Kolkata, which will be able to generate 5.66 Gg CH_4 per year till 2034.

For domestic and commercial wastewater diversification of treatment pathways with methane recovery from sewage are considered. As discussed in Table 6, this scenario considers sewage pathway utilization as 46% for rural, 82% for urban high income group, and 69% for rural income group by 2031, with sewage sludge digestion and methane flaring through sewage pathway increasing as 25% in 2021 and 33% in 2031. While utilization of treatment pathways remained constant to the level of 2011 in RES scenario, with negligible recovery of methane.

Table 6: Fraction of Utilization Of Treatment Pathways In Mitigation Option 1.

Parameters	Domestic	Septic tank	Laterine	Sewer	Other	None
Rural						
2021	-	0.06	0.3	0.33	0.09	0.22
2031	-	0.10	0.22	0.46	0.08	0.14
Urban high						
2021	-	0.15	0.05	0.75	0.05	-
2031	-	0.13	0.03	0.82	0.02	-
Urban low						
2021	-	0.15	0.08	0.62	0.02	0.13
2031	-	0.16	0.06	0.69	0.01	0.08

- Negligible

For industrial treatment plants, better reuse of methane generated, within premises, for cogeneration has been considered. This scenario also gives an accelerated push for diversifying the treatment pathways and thereby increasing renewable technologies and penetration of new technologies (Table 7) while in RES these remain constant at the level in 2011.

Table 7: Percentage of Methane Recovery And Reuse From Industries Under Mitigation Option 1

Industry	2011	2021	2031
Pulp and paper	-	15%	31%
Sugar	70%	75%	77%
Beer	75%	80%	82%
Dairy	75%	80%	82%

- Negligible

3.2.2 Mitigation Option 2 (aggressive)

More aggressive mitigation measures are deployed for LFG recovery, and organic waste diversion from landfills to reduce the GHG emissions from waste sector of the country by 2031. Diversion of organic waste from landfills to treatment plants as 30% by 2021 and 55% by 2031 are considered. Four landfill sites—Ghazipur (Delhi), Dhapa (Kolkata), Gorai (Mumbai), and Uruli (Pune)—are considered to ensure landfill gas capture facility estimates reduction of CH_4 by 13.74 Gg by 2021, and Shadara (Agra) landfill has been considered with LFG capture by 2026, and estimates reduction of CH_4 by 9.87 Gg.

Diversification of treatment pathways for domestic and commercial wastewaters with methane recovery from sewage is deliberated. Utilization of sewage pathway in range of 46% for rural income, 83% for urban high income, and 70% for urban low income groups by 2031 has been considered (Table 8). Also, methane recovery through sewage pathway is considered as 30% by 2021 and 50% by 2031.

Table 8: Fraction of Utilization of Treatment Pathways Under Mitigation Option 2

Parameters	Domestic	Septic tank	Laterine	Sewer	Other	None
			Rural			
2021	-	0.06	0.30	0.33	0.09	0.22
2031	-	0.08	0.24	0.46	0.08	0.14
			Urban high			
2021	-	0.15	0.05	0.75	0.05	-
2031	-	0.11	0.03	0.83	0.03	-
			Urban low			
2021	-	0.15	0.08	0.62	0.02	0.13
2031	-	0.14	0.06	0.7	0.01	0.09

- Negligible

For industrial treatment pathways, this scenario assumes faster implementation of better treatment technologies with increased recovery and reuse of methane in industries till 2031 as described in Table 9.

Table 9: Percentage Of Methane Recovery And Reuse From Industries Under Mitigation Option 2

Industry	2011	2021	2031
Pulp and paper	-	20%	40%
Sugar	70%	75%	79%
Beer	75%	80%	84%
Dairy	75%	80 %	84%

- Negligible

Fig 2 presents' estimated GHG emissions from waste sector in mitigation option 1 and mitigation option 2 scenarios, along with RES. Under mitigation scenarios, the GHG emissions can be reduced by 20.73% with mitigation option 1 and 29.90% with mitigation option 2 from the RES level in 2031. In mitigation option 2 scenarios, out of total GHG mitigation of 33.58 million tonnes CO_2 eq. in 2031, industrial wastewater contribute to 21.93 million tonnes CO_2 eq reduction, followed by solid waste with 7.61 million tonnes CO_2 eq.

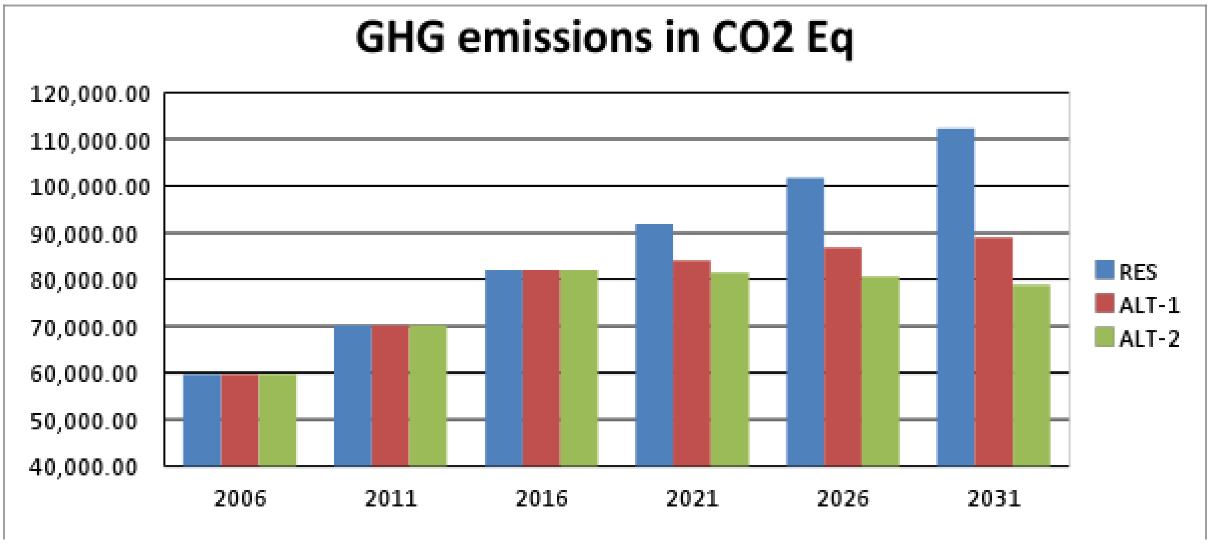


Figure 2: GHG emission pattern from waste sector in India (thousand tonnes)

The annual per capita protein consumption and population are the drivers for nitrous oxide emission from domestic and commercial wastewater treatments. Nitrous oxide is directly linked with a fraction of undigested protein discharged by humans into wastewater. Since similar socio-economic parameters are assumed in all three scenarios, therefore, projection for N_2O emissions also found similar in mitigation option scenarios.

4. Conclusion

The amount of GHG emissions from India's waste sector is only about 3% compared to total GHG emission, yet this can be substantially reduced. Based on review and modelling estimates, it can be concluded that diversion of organic waste from landfills towards treatment options, diversion of wastewater from domestic and commercial sectors towards sewer, and further capturing and utilising methane are a few alternatives that can help reduce the peak of GHGs by 11.19 % in 2021 and 29.89 % in 2031. Industries like pulp & paper, beer, sugar, and dairy can capture methane through effluent treatment units and reduce a major fraction of GHG emissions. There is an urgent need to apply appropriate policy, political will, financial resources, capacity building, and indigenous technology to reduce impact of our activities on global warming. Further, there is a need to have higher tier studies to work out the actual reduction in GHGs from our activities, so as to prioritize mitigation strategies. This paper is a first of its kind, estimating the emission for future and implication of pathways to reduce these emissions, setting an impetus to formulate policies to reduce GHG emissions from waste sector.

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References

[1] Ministry of Environment, Forests and Climate Change. (2017). *Consolidated Annual review report on implementation of solid waate management rules, 2016.* Central Pollution Control Board. New Delhi: CPCB.

[2] Siddiqui, F. Z. (2013). Evaluation of energy potential from unsecure landfill site in India. JMI University, Mechanical Engineering. New Delhi: Jamia Millia Islamia.

[3] Central Pollution Control Board. (n.d.). *www.cpcb.nic.in.* Retrieved November 10, 2016, from Waste generation and compositionr: http://cpcb.nic.in/uploads/hwmd/Waste_generation_Composition.pdf

[4] Planning Commission. (2014). Report of the Task Force on Waste to Energy (Volume-1). Planning Commission, PPP and Infrastructure Division. New Delhi: Planning Commission.

[5] Schneider, W. J. (1970), Hydrologic Implications of Solid-Waste Disposal. U.S. Department of the Interior, U.S. Geological Survey. Alexandria, Verginia: U.S. Geological Survey

[6] Planning Commission. (2014). Report of the Task Force on Waste to Energy (Volume II). Planning Commission, PPP and Infrastructure Division. New Delhi: Planning Commission.

[7] Central Pollution Control Board. (2015). Inventorization of Sewage Treatment Plants. Ministry of Environment and Forests, Government of India. New Delhi: Central Pollution Control Board.

[8] Ministry of Environment & Forests.(2012). India Second National Communication to UNFCCC. UNFCCC. New Delhi.

[9] Intergovernmental Panel on Climate Change. (2006). 2006 Guidelines for National Greenhouse Gas Inventories. Waste, 5. (L. B. Simon Eggleston, Ed.) Hayama, Japan: Institute for Global Environmental Strategies (IGES).

[10] World Health Organization. (n.d.). Availability and changes in consumption of animal products. Retrieved January 23, 2016, from World Health Organization: http://www.who.int/nutrition/topics/3_foodconsumption/en/index4.html

[11] Ministry of Environment, Forest and Climate Change. (2013). Evaluation of energy potential from unsecured landfill site. New Delhi: Ministry of Environment, Forest and Climate Change.

