

# Chapter 4

## Quantification of Landfill Gas Emission and Energy Recovery Potential: A Comparative Assessment of LandGEM and MTM Model for Kolkata



**Babul Das and Tumpa Hazra**

**Abstract** Solid waste management (SWM) and disposal is a major environmental concern in recent times and is getting rapidly complicated day by day. In developing countries, municipal solid waste (MSW) is generally disposed of through open dumping and landfilling in semiengineered landfills resulting in the generation of a huge amount of greenhouse gases like CO<sub>2</sub> and CH<sub>4</sub>. Methane has the highest climate change impact (5.94 kg CO<sub>2</sub>eq/KWhe). Again, methane can be used as a renewable energy source since its energy generation potentiality is 37.2 MJ/m<sup>3</sup>.

The objective of this study is to estimate and compare the emission of landfill gas (LFG) from an uncontrolled landfill site, located in Dhapa, Kolkata, India using LandGEM (3.02) and the modified triangular method (MTM) model. The energy generation potential of the generated landfill gas is also assessed. It is estimated that methane emission varies from 10.87 to 24.01 Mm<sup>3</sup>/year and 28.36 to 44.23 Mm<sup>3</sup>/year using LandGEM and the MTM model, respectively, for the period of 2010–2030. It is also estimated that the annual power generation from LFG emissions varies from 18.045 to 39.858 MWh and 47.079 to 73.424 MWh using the estimates of LandGEM and the MTM model, respectively, for the same period.

**Keywords** Municipal solid waste disposal · Landfill gas emission · Greenhouse gas · Methane emission estimation · LandGEM · MTM · Energy recovery potential

### 4.1 Introduction

Solid wastes (SWs) are the discarded solid materials generated through the use of resources of the earth by humans and animals to support their life. It may be generated through residential activities, commercial activities, industrial activities,

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B. Das · T. Hazra (✉)  
Jadavpur University, Kolkata, India

institutional works, construction and demolition works, and agricultural activities (Tchobanoglous et al. 1993). Development of a sustainable management plan for solid waste (SW) is a serious challenge to policy makers now a days, mainly for developing countries, since total solid waste generation escalates with the growth in the total population of the area. Again, with the rapid industrialization, level of urbanization, economic development, and changing consumption patterns, per capita municipal solid waste (MSW) generation increases rapidly. About  $2.01 \times 10^9$  tons of MSW was generated globally in 2016 and expected to become  $3.4 \times 10^9$  tons in 2050 (Kaza et al. 2018). About 19.86 million tons of MSW is generated in urban India per year (Annual Report 2018–19, MoEFCC). Major parts of the MSW (>70%) of the developing countries are organic in nature, which is readily degradable (Ramachandra et al. 2018). In spite of the growing practice of resource conservation and recycling of waste and stringent rules against waste disposal, the landfilling method is still widely used for final waste disposal due to process simplicity and low economic investment worldwide. In India, about 51% of 83% collected MSW are dumped in landfill sites without any treatment and with a negligible amount of daily cover (Annual Report 2018–19, MoEFCC). One of the consequences of solid waste disposal in landfills is the generation of landfill gas (LFG), a serious environmental threat since it is composed of 45–60% (V/V) methane and 40–55% (V/V) carbon dioxide (USEPA 2014). Methane emission from solid waste disposal sites is computed as 3–19% of the total anthropogenic methane generation, and it is the third major anthropogenic source of CH<sub>4</sub> (IPCC 1996). In the year 2014, India emitted 16 Mg CO<sub>2</sub> eq of methane, which is expected to reach 20 Mg CO<sub>2</sub> eq by the year 2020 (Kumar and Sharma 2014). Methane generation from India contributes about 29% of the total greenhouse gas (GHG) emission of the country (Ghosh et al. 2019; Kumar and Sharma 2014; Siddiqui et al. 2006). The increase in GHG emissions can lead to an increase in global temperature and threaten human life and the environment (Hughes 2000). As LFG is one of the major sources of GHGs, proper management of LFG can reduce GHG emission into the atmosphere. Collection and flaring or oxidizing in biofilters is one of the possible management options of LFG. Since energy generation potential of CH<sub>4</sub> is 37.2 MJ/m<sup>3</sup> (Cudjoe and Su 2020), another possible management option is LFG collection and using it as a renewable waste to energy source. For implementation of these management systems, it is essential to quantify the LFG emission from the landfill site.

The literature revealed very little work on the estimation of landfill gas emission in Kolkata region. Again, whatever works have been done so far considered the default model parameters. Locality-specific parameters like rate constant of methane generation ( $k$ ) and potential of methane yield ( $L_0$ ) from waste are required to be calculated for the Kolkata region since these parameters are very important for accurate determination of landfill gas emission. Again, estimation of global warming potential and energy generation potential from landfill gas emission are also required to make decision about developing any sustainable management plan. So, estimation and comparison of landfill gas (LFG) emission and energy recovery potential of the Dhapa landfill site located at Kolkata using LandGEM (3.02) and the modified triangular method (MTM) is the main aim of this paper.

## 4.2 Materials and Methods

### 4.2.1 Study Area

This study was conducted in Kolkata (latitude 22°34' N and longitude 88°24' E), the largest metropolitan city in eastern India. It is located on the east bank of River Hooghly and is 30 km away from the Bay of Bengal with an average elevation of 17 feet above the mean sea level. The rate of generation of municipal solid waste in Kolkata is about 470 gcpd (gram per capita per day) for the 4.5 million resident population and 250 gcpd for the six million floating population resulting about 3520 tons of municipal solid waste generation daily (Ali 2016). The waste is mainly biodegradable in nature (50.56%) with high moisture content (46%) and low calorific value (1201Kcal/kg) (Chattopadhyay et al. 2009; KMC, 2019). Presently in Kolkata, these wastes are directly disposed of at different disposal sites located around the city without any segregation and prior treatment. The Kolkata Municipal Corporation (KMC) runs three disposal sites located at Dhapa, Garden Reach, and Naopara. The Dhapa disposal site is located at eastern Kolkata on an average 20 km away from all the collection points and accepts about 95% of the total solid waste generated in the KMC area (Hazra and Goel 2009). Presently, 24.47 ha area is used at Dhapa for MSW disposal. The total area of the Dhapa MSW disposal site is 24.47 ha. It is an open dumpsite without any liner or leachate or gas collection and management system. The landfill is overexploited since the height of disposed waste (more than 20 m from ground level) exceeds the designed slope and life. However, this landfill site is still under operation and receives about 3000–3200 T of solid waste per day from both KMC's public waste haulers and private haulers. The present study deals with the LFG emission potential of the Dhapa disposal site. LandGEM (3.02) and the modified triangular method (MTM) were applied to estimate and compare the quantity of LFG generated from the Dhapa disposal site. The energy generation potential of LFG has also been calculated. Salient features of the Dhapa disposal site are presented in Table 4.1.

### 4.2.2 Prediction of Disposed MSW in Dhapa

Estimation of GHG generation from landfill requires accurate prediction of SW disposed in the landfill, considering that the 100% generated SW is disposed in landfill. For estimation of landfill gas emission, historical data on MSW disposed to the landfill site from the starting year to the year of closure of disposal site are required. The starting year of the Dhapa disposal site was 1981, and the closure year is 2020. The available waste disposal data for 2001 to 2012, obtained from the paper of SCS Engineers 2010, were used to predict waste disposal in the Dhapa landfill site for the year 2013–2020 using the geometric increase method. From Table 4.2, it is obtained that the annual average increases in solid waste disposal rate of 13.44%. By

**Table 4.1** Salient features of the Dhapa open dumpsite, Kolkata, India (SCS Engineers 2010)

Characteristics	Dhapa landfill site
Starting year	1980
Year of closure	2020
Waste management facility	Daily spreading and compaction
Area (ha)	34.2
Climate	Tropical and rainy
Humidity	52%–82%
Average height (m)	30
Dumping quantity (TPD)	3500
Annual precipitation (mm/year)	1770
Temperature(°C)	26.1
LFG collection system	No gas collection system
Soil cover	Little or no

**Table 4.2** Waste disposal data used for prediction of the waste disposal rate

Year	Annual waste disposal (Mg)	% annual increase rate	Average annual increase rate (%)
2000	256,200	–	13.44
2001	294,600	14.98	
2002	338,800	15.00	
2003	389,600	14.99	
2004	448,000	14.98	
2005	515,200	15.00	
2006	592,500	15.00	
2007	681,400	15.00	
2008	912,000	33.8	
2009	1,277,500	40.10	
2010	1,303,100	2.0	
2011	1,329,200	2.0	
2012	1,042,100	–21.6	

using this rate, the solid waste disposal data between the years 2013–2020 are predicted and used for GHG emission estimation.

### 4.2.3 Selection of LFG Emission Models

The rate of gas production in landfills can be estimated by modeling. The gas production in the disposal site relies on the decomposition rate of the organic matter. The decomposition of the organic materials depends on the order of the reaction that takes place in the landfill. Based on the order of reaction, different models are developed viz. zero-order models, first-order models, and second-order models. As most of the biological reactions are first order, first-order models are extensively

used for estimating LFG emission. The available models for estimation of LFG emission are IPCC DM, IPCC FOD models, LandGEM, TNO model, TM, MTM, EPER Germany model, SWANA model, Multiphase model, etc. Many Indian researchers used different models to calculate the LFG production from MSW disposal sites, and it is concluded that LandGEM gives more realistic results in Indian conditions than other models. LandGEM (3.02) is a first-order model, and the most important parameters for the model are the rate constant of CH<sub>4</sub> generation ( $k$ ) and methane yield ( $L_0$ ). To determine the value of model parameters such as rate constant of methane production ( $k$ ), methane yield ( $L_0$ ), etc. accurately, information like historical waste quantities, composition, characteristics, waste disposal practices, temperature variation, rainfall variation, distribution of waste, moisture content, compaction and density of waste, etc. are required.

Since the historical data on waste composition, characteristics, quantities, disposal, and management practices are not available for Indian conditions, the LandGEM model may not give an accurate estimation of methane emissions. In the absence of detailed information about the waste components, distribution, characteristics, disposal procedures and statistical data on temperature, rainfall, waste generation, and information about landfill management practice, the MTM method of gas estimation can be adopted (Kumar et al. 2004). Hence, in the present work, the MTM model is also adopted along with the LandGEM (3.02) model for the assessment of LFG emissions from the MSW dumping site at Dhapa.

#### 4.2.4 LandGEM (3.02)

The Landfill Gas Emission Model (LandGEM) developed by USEPA (2005) is widely used for estimating the generation of methane from the degradation of MSW in landfills over time. The LandGEM (3.02) model uses the first-order decay rate equation for the assessment of LFG generation from the degradation of MSW in disposal sites. The methane production rate attains its maximum value very rapidly after the MSW is disposed to the disposal site and decreases slowly during the next period of degradation. Eq. (1) shows the decomposition rate equation used to quantify the rate of methane generation ( $Q$ , m<sup>3</sup>/year).

$$Q_{CH_4} = \sum_{i=1}^n \sum_{j=0.1}^1 kL_0 \left( \frac{M_i}{10} \right) e^{-kt_{ij}} \quad (4.1)$$

$L_0$  = methane yield (m<sup>3</sup>/Mg).

$i$  = increment of time (1 year).

$n$  = (year of estimation) - (year of first waste disposal).

$j$  = increment of time (0.1 year).

$k$  = first order rate constant of methane generation (year<sup>-1</sup>).

$M_i$  = mass of MSW deposited in the  $i^{\text{th}}$  year (Mg).

$t_{ij}$  = age of the  $j^{\text{th}}$  section of waste mass  $M_i$  accepted in the  $i^{\text{th}}$  year.

The model assumes that total LFG consists of 50% of methane and 50% of carbon dioxide with the presence of nonmethanogen organic carbons and other pollutants. Furthermore, one can use a specified value of methane content within the value of 40–60%. In the present study, it is assumed that LFG consists of CH<sub>4</sub> by 55% and CO<sub>2</sub> by 45% along with trace constituents of nonmethanogenic compounds and other pollutants. The carbon dioxide generation ( $Q_{CO_2}$ ) is quantified from the production of methane ( $Q_{CH_4}$ ) and the percentage of methane content ( $P_{CH_4}$ ) using Eq. (2).

$$Q_{CO_2} = Q_{CH_4} \left[ \left\{ \frac{1}{\frac{P_{CH_4}}{100}} \right\} - 1 \right] \quad (4.2)$$

To estimate landfill gas generation from a disposal site using LandGEM, it is required to input different parameters like rate constant of methane generation, opening year of landfill, closing year of landfill, CH<sub>4</sub> yield, and waste disposal rates (Mg/year) (USEPA 2005).

#### 4.2.5 Evaluation of Rate Constant for Methane Generation (K)

The rate constant for methane generation ( $k$ ) represents CH<sub>4</sub> production rate and decay of solid waste in the disposal site. The prediction of time over which methane is produced from a particular waste stream is controlled by the value of the rate constant of the decomposition (Amini et al. 2012). The rate constant is primarily a function of four factors: available moisture content, pH, nutrients availability for degrading microorganisms, and temperature of the waste mass.

There are different methods for evaluation of  $k$  value. The laboratory simulation method (De la Cruz and Barlaz 2010; Wang and Barlaz 2016) is used for computation of  $k$  value in the present study.

#### 4.2.6 Laboratory Simulation Method

Each waste component has different decay rates. First  $k$  values of individual waste component are determined in laboratory condition ( $k_{lab}$ ) by experiment, and after that, the  $k$  value of MSW ( $k_{lab,MSW}$ ) is computed by taking weighted average of  $k$  values of individual waste component. Laboratory  $k$  values are generally higher in magnitude than field conditions since laboratory situations are more perfect. Karanjekar et al. (2015) presented a correction factor ( $f$ ) on the basis of annual average precipitation and average temperature to convert the laboratory  $k$  values of MSW component into field  $k$  values ( $k_{field, i}$ ).

**Table 4.3** Different waste composition in Kolkata and corresponding k value

Composition	% waste <sup>a</sup>	k <sub>lab</sub> (y <sup>-1</sup> ) <sup>b</sup>	f value <sup>c</sup>	k <sub>field</sub> (y <sup>-1</sup> ) <sup>d</sup>
Food waste	45.5	15.02	0.0046	0.07
Branches/wood	1.2	1.56	0.0046	0.007
Green waste (leaves+grass)	5	24.5	0.0046	0.11
Textiles	4	3.08	0.0046	0.014
Paper	4	3.27	0.0046	0.015
Other organics	3.4	13.68	0.0046	0.06

(a) Engineers 2010 (b) De la Cruz and Barlaz 2010 (c) Eq. 4.5 (d) Eq. 4.4.

$$k_{\text{fieldMSW}} = f \left\{ \sum k_{\text{lab},i} \times (\text{wt. fraction})_i \right\} \quad (4.3)$$

$$k_{\text{field},i} = f \times k_{\text{lab},i} \quad (4.4)$$

$$f = -0.00758 T + 0.0135 R + 0.137 \quad (4.5)$$

where  $i$  is the  $i^{\text{th}}$  waste component,  $T$  is the ambient temperature ( $^{\circ}\text{C}$ ), and  $R$  is the average annual precipitation (mm/day).

Table 4.3 shows the fraction of different waste components present in MSW of Kolkata and their corresponding  $k$  value.

It is estimated that the  $k$  value of MSW in the field for Kolkata is  $0.04 \text{ y}^{-1}$  using Eq. 4.3. Kumar and Sharma (2014) used  $k$  value as  $0.07 \text{ y}^{-1}$  for the assessment of  $\text{CH}_4$  emission from the MSW landfill site.

#### 4.2.7 Evaluation of Methane Generation Potential ( $L_0$ )

$L_0$  is the quantity of methane ( $\text{m}^3$ ) produced per megagram of MSW decomposition under idealized conditions for methane generation. The composition and type of waste disposed in the disposal site controls the value of methane yield.  $L_0$  value is calculated based on per megagram of dry waste. So, dry waste should be considered for calculation of methane yield. In our study, we use the data of moisture content reported in IPCC (2006) for the computation of methane yield. For calculation of  $L_0$  value of a landfill, it is assumed that the  $L_0$  value of a waste mix is equal to the weighted average  $L_0$  value of individual waste component. Ultimate methane yield and moisture content of various waste components are shown in Table 4.4. It is calculated that Kolkata has an  $L_0$  value of  $46.51 \text{ m}^3/\text{Mg}$ .

#### 4.2.8 Modified Triangular Method (MTM)

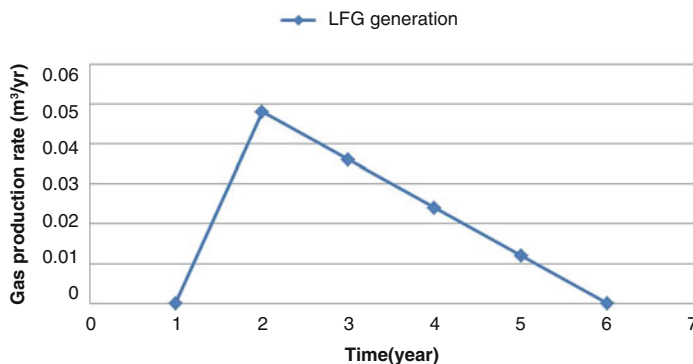
Triangular method is based on the first-order decomposition methodology with modification of the total amount of landfill gases generated from the waste

**Table 4.4** Moisture content and ultimate CH<sub>4</sub> yield of different waste components (Staley and Barlaz 2009)

Waste categories	Moisture content (%) [8]	Ultimate CH <sub>4</sub> yield (L <sub>0</sub> ) (m <sup>3</sup> /Mg)
Compostable matter <sup>a</sup>	45	145.1
Paper <sup>a</sup>	10	132.8
Textile	20	14.8

<sup>a</sup>Average of newspaper, office paper, glossy paper, and old corrugated containers (OCC)/Kraft bags

<sup>b</sup>Average of food waste, green waste, and wood waste

**Fig. 4.1** Triangular gas production for RBW of Kolkata

represented by the area of triangle for a particular period of time; i.e., the rate of gas emission is linear rather than exponential (Tchobanoglous et al. 1993). Modified triangular method (MTM) is slight modification to the triangular method. In this method, it was assumed that the total LFG production is equal to the gas estimated by the default methodology. The peak rate of gas generation is calculated by equating the landfill gas estimate obtained from IPCC default methodology and the area of triangle. In this model, the biodegradable organic materials present in MSW are separated into two parts: (1) rapidly biodegradable waste (RBW) and (2) slowly biodegradable waste (SBW) (Tchobanoglous et al. 1993). The rapidly degradable wastes of MSW consist of food waste, paper, and a portion of yard wastes and the slowly degradable wastes of MSW consisting of rubber, leather, woody portions of yard waste, and wood (Tchobanoglous et al. 1993). It is assumed that the MSW starts gas production after 1 year of deposition. Gas emission from the RBW reaches a maximum in the second year after waste deposition and gradually decreases to zero at the end of the sixth year; i.e., gas emission from RBW takes place over a period of 5 years. For the SBW, gas generation starts at the end of the first year and reaches the peak after 6 years of waste deposition and then gradually decreases to zero after the sixteenth year; i.e., gas emission for SBW takes place over a period of 15 years. The rate and amount of gas generated at the end of each year from 1 kg rapidly biodegradable and slowly biodegradable organic matter are shown in Figs. 4.1 and 4.2.



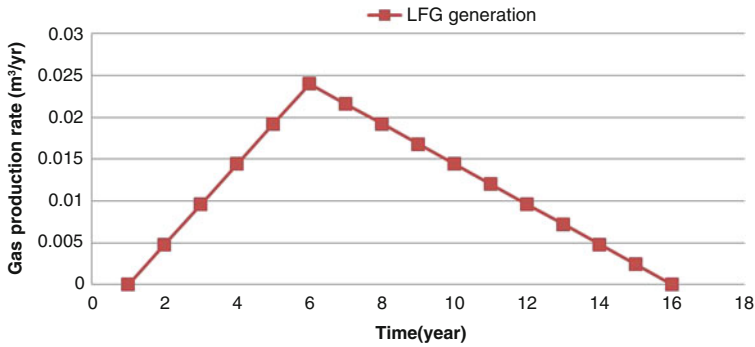


Fig. 4.2 Triangular gas production for SBW of Kolkata

Table 4.5 Parameters used for evaluating energy generation potential from landfill gas

Parameter	Value considered
Low calorific value of CH <sub>4</sub> (MJ/m <sup>3</sup> )	37.2 (Cudjoe and Su 2020)
Oxidation factor in landfill	0.9 (IPCC 2006)
Energy generation efficiency of gas engine	30% (Ghosh et al. 2019)
Capacity factor	0.85 (Cudjoe and Su 2020)
Landfill gas collection efficiency	70% (Ghosh et al. 2019)

The total rate of gas generation from a landfill in which wastes were placed is obtained graphically by summing the amount of gas generation from RBW and SBW portions of MSW deposited each year.

### 4.2.9 Evaluation of Energy Generation Potential of Landfill Gas

The amount of methane generation as predicted for 2010 to 2030 using both LandGEM (3.02) method and MTM method was used to evaluate the energy generation potential using Eq. 4.6 (Cudjoe and Su 2020).

$$\begin{aligned}
 &\text{Energy Generation Potential of Methane from Landfill Site (MJ/yr)} \\
 &= \text{Generated CH}_4 \text{ (m}^3\text{/yr)} / \times \text{Low calorific value of CH}_4 \text{ (MJ/m}^3\text{)} \\
 &\quad \times \text{Oxidation factor in the landfill} \\
 &\quad \times \text{Energy generation efficiency of the gas engine} \times \text{Capacity factor} \\
 &\quad \times \text{Landfill gas collection efficiency} \tag{4.6}
 \end{aligned}$$

After the estimation of the energy generation potential of methane in MJ, it was multiplied by 0.2778 to convert it into MWh.

To calculate the amount of energy generation potential of LFG from the Dhapa landfill site, the data which were assumed are presented in Table 4.5.

### 4.3 Results and Discussion

The predicted solid waste disposed at the Dhapa landfill site for 2013–2020 was used for landfill gas estimation. Using the LandGEM (3.02) method, it is found that the total LFG, CH<sub>4</sub>, and CO<sub>2</sub> emission during the period 2010–2030 are 716.35 Mm<sup>3</sup>, 393.99 Mm<sup>3</sup>, and 322.33 Mm<sup>3</sup>, respectively. Fig. 4.3 shows the LFG emission over the period of 1981–2100 from the Dhapa open dumpsite. It is also shown that maximum emission takes place in the closure year, i.e., in the year 2020. Using the MTM method, it is found that the total LFG, CH<sub>4</sub>, and CO<sub>2</sub> emission during the period 2010–2030 are 1160.73 Mm<sup>3</sup>, 638.40 Mm<sup>3</sup>, and 522.32 Mm<sup>3</sup>, respectively. Fig. 4.4 shows the LFG emission over the period of 1981–2035 from the Dhapa open dumpsite. It is also shown that maximum emission takes place 2 years after the closure year, i.e., in the year 2022.

It is seen that methane emission obtained using the MTM model is 62.1% greater than the methane emission using the LandGEM version 3.02 model. In the MTM method, it is assumed that the total LFG emission occurs from MSW, disposed in a year, within a base period of 16 years from the time of disposal. Again, this method assumes linear variation of LFG emission, but actually, the variation of landfill gas emission follows an exponential distribution due to first-order biological reaction. These assumptions may lead to a higher result.

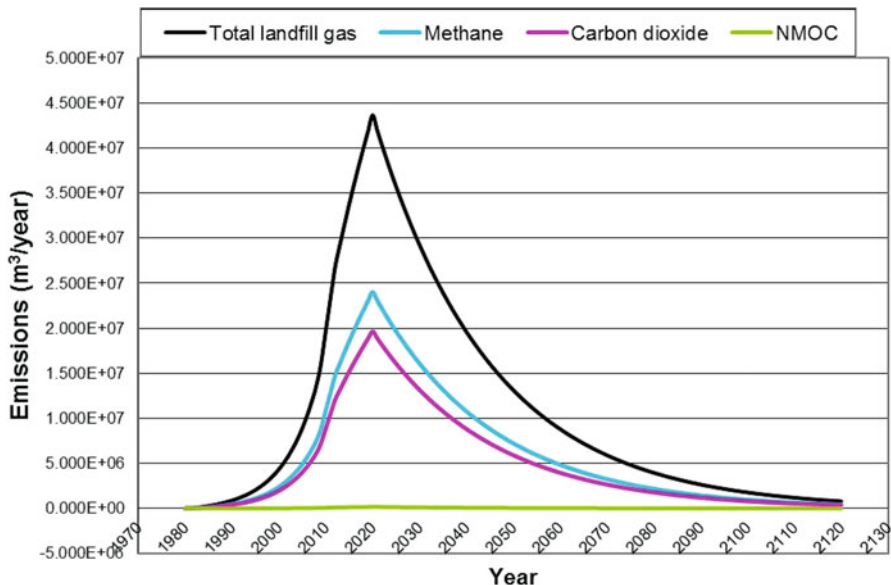


Fig. 4.3 LFG emissions from the Dhapa open dumpsite by LandGEM

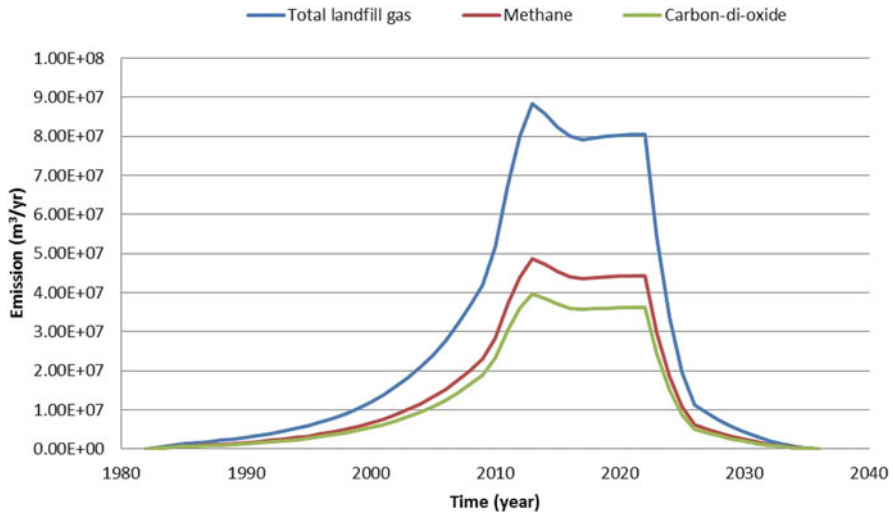


Fig. 4.4 LFG emissions from the Dhapa open dumpsite by MTM

It is also estimated that methane emission varies from 10.87 to 24.01  $\text{Mm}^3/\text{year}$  and 28.36 to 44.23  $\text{Mm}^3/\text{year}$  using LandGEM (3.02) and the MTM method, respectively, for the period of 2010–2030 from the Dhapa landfill site in Kolkata.

From the LFG emission curves, it is shown that the highest rate of gas emission occurs between the period 2010 to 2030. So, the present study shows the value of LFG emission between the periods of 2010–2030. But, gas emission also takes place beyond this time period, although the emission rate is less. After the closure year, the LFG emission rate decreases faster than the LFG emission rate before the closure year. From the LFG emission graphs, it is also obtained that considerable LFG emission takes place during the period of 10–15 years after the closure year.

From the  $\text{CH}_4$  emission calculated by the LandGEM (3.02) method, it is estimated that annual energy generation varies from 64.961 TJ to 143.488 TJ ( $1 \text{ TJ} = 10^{12} \text{ J}$ ) and power generation varies from 18.045 MWh to 39.858 MWh, which is about 1–2% of the power demand of Kolkata city. By using  $\text{CH}_4$  emission from the MTM method, it is seen that annual energy generation varies from 169.484 TJ to 264.326 TJ ( $1 \text{ TJ} = 10^{12} \text{ J}$ ) and power generation varies from 47.079 MWh to 73.424 MWh, which is about 2.2–3.5% of the power demand of Kolkata city. Presently, the electric supply of Kolkata city is fully dependent on coal-based thermal power plants. Generation of electricity from LFG reduces the dependency on using non-renewable energy sources. Furthermore, the emission of GHG and other air pollutants due to combustion of fossil fuel and direct emission from landfills can be decreased. The reduction of GHG also helps Kolkata Municipal Corporation to earn revenue by trading the certified emission reduction (CER) credits under the clean development mechanism (CDM) project.

## 4.4 Conclusion

MSW disposal sites are major sources of GHG emission to the atmosphere. The present investigation revealed that methane emission from the Dhapa open dumpsite of Kolkata varies from 10.87 to 24.01 Mm<sup>3</sup>/year by using LandGEM (3.02) and 28.36 to 44.23 Mm<sup>3</sup>/year estimated by using the MTM model for the period of 2010–2030. Presently, this huge amount of GHGs is directly emitted to the atmosphere and causes the greenhouse effect, which leads to global warming and different undesirable effects on the environment. Again, LFG has high energy potential and can be used as fuel for power generation. Generated electricity can be used in landfill itself for operating electric equipment, lighting, etc. The budget savings for electricity can be considered as revenue. The generated electricity can be used as a revenue generator by supplying electricity in the national grid. The revenue obtained from the energy project can be used for developing the solid waste management system, which supports environmental sustainability. This management process also supports the economy of the country and gives a renewable energy source. Environmental benefits can also be claimed through reducing GHG emission.

However, there are certain limitations in the present study. Most of the data used in this study were secondary data, collected from different published papers. For realistic estimation in Indian conditions, a detailed investigation is required to determine the congenial factors affecting LFG generation and their variations. A detailed environmental and economic assessment is required to be done before implementation of landfill gas to energy project for the Dhapa landfill area.

## References

- Ali SKA (2016) Status of solid waste generation and management practice in Kolkata municipal corporation, West Bengal. *Int J Environ Sci* 6(6)
- Amini HR, Reinhart DR, Mackie KR (2012) Determination of first-order landfill gas modelling parameters and uncertainties. *Waste Manag* 32:305–316
- Annual Report (2018–19) MoEFCC obtained from [https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKewjPxsDppY3rAhW\\_wzgGHRsNCB4QFjAFegQICBAB&url=http%3A%2F%2Fmoef.gov.in%2Fwp-content%2Fuploads%2F2019%2F08%2FAnnual-Report-2018-19-English.pdf&usg=AOvVaw1VWtc7aWZ3Mtqr\\_qsjqI\\_X](https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKewjPxsDppY3rAhW_wzgGHRsNCB4QFjAFegQICBAB&url=http%3A%2F%2Fmoef.gov.in%2Fwp-content%2Fuploads%2F2019%2F08%2FAnnual-Report-2018-19-English.pdf&usg=AOvVaw1VWtc7aWZ3Mtqr_qsjqI_X). Accessed 9th August, 2020
- Chattopadhyay S, Dutta A, Ray S (2009) Municipal solid waste management in Kolkata, India- a review. *Waste Manag* 29:449–458
- Cudjoe D, Su HM (2020) Economic and environmental assessment of landfill gas electricity generation in urban districts of Beijing municipality. *Sustainable Production and Consumption* 23:128–137
- De la Cruz FB, Barlaz MA (2010) Estimation of waste component specific landfill decay rates using laboratory-scale decomposition data. *Environ Sci Technol* 44:4722–4728

- Ghosh P, Shah G, Chandra R, Sahota S, Kumara H, Vijaya VK, Thakur IS (2019) Assessment of methane emissions and energy recovery potential from the municipal solid waste landfills of Delhi, India. *Bioresour Technol* 272:611–615
- Hazra T, Goel S (2009) Solid waste management in Kolkata, India: practices and challenges. *Waste Manag* 29:470–478
- Hughes L (2000) Biological consequences of global warming: is the signal already apparent? *Trends Ecol Evol* 15(2):56–61
- IPCC (1996) Report of the twelfth session of the intergovernmental panel on climate change, intergovernmental panel on climate change (IPCC). Mexico City:11–13
- IPCC (2006) IPCC guidelines for national greenhouse gas inventories. In: Task force on national greenhouse gas inventories Cambridge, vol. 5 U.K. and New York, NY, USA
- Karanjekar RV, Bhatt A, Altouqui S et al (2015) Estimating methane emissions from landfills based on rainfall, ambient temperature, and waste composition: the CLEEN model. *Waste Manag* 46:389–398
- Kolkata Municipal Corporation (2019) Solid waste management activities in Kolkata City. [https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKewjK2rOxtYnrAhXN7XMBHSBLAhQQFjADegQIAhAB&url=https%3A%2F%2Fwww.kmccgov.in%2FKMCCPortal%2Fdownloads%2FPublic\\_domain\\_Statis\\_report\\_SWM\\_28\\_10\\_2019.pdf&usq=A0vVaw00ooM0ItMHZ6zcOuuPykvl](https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKewjK2rOxtYnrAhXN7XMBHSBLAhQQFjADegQIAhAB&url=https%3A%2F%2Fwww.kmccgov.in%2FKMCCPortal%2Fdownloads%2FPublic_domain_Statis_report_SWM_28_10_2019.pdf&usq=A0vVaw00ooM0ItMHZ6zcOuuPykvl). Accessed on 7.8.2020
- Kumar A, Sharma MP (2014) GHG emission and carbon sequestration potential from MSW of Indian metro cities. *Urban Clim* 8:30–41
- Kumar, S., Mondal, A.N., Gaikwad, SA Devotta, S., (2004) Qualitative assessment of methane emission inventory from municipal solid waste disposal sites: a case study. *Atmospheric Environ* (38):4921–4929
- Ramachandra TV, Bharath HA, Kulkarni G, Han SS (2018) Municipal solid waste: generation, composition and GHG emissions in Bangalore, India. *Renew Sust Energ Rev* 82:1122
- Engineers SCS (2010) Methane to markets assessment report, Dhapa disposal site Kolkata. Kolkata Municipal Corporation, Kolkata
- Siddiqui TZ, Siddiqui FZ, Khan E (2006) Sustainable development through integrated municipal solid waste management (MSWM) approach – a case study of Aligarh District. In: Proceedings of National Conference of advanced in mechanical engineering (AIME-2006). Jamia Millia Islamia, New Delhi, India, pp 1168–1175
- Staley BF, Barlaz MA (2009) Composition of municipal solid waste in the United States and implications for carbon sequestration and methane yield. *J Environ Eng* 135:901–909
- Tchobanoglous G, Theisen H, Vigil SA (1993) Integrated solid waste management: engineering principles and management issues. McGraw Hill, International editions
- USEPA (United States Environmental Protection Agency) (2005) Landfill Gas Emissions Model (LandGEM version 3.02): Version 3.02, User's Guide, EPA-600/R-05/047, <http://www.epa.gov/ttn/catc/dir1/LandGEMversion3.02-v302-guide.pdf>, USA
- USEPA (2014) U.S Energy Information Administration. Monthly energy review. Washington DC 2015
- Wang X, Barlaz MA (2016) Decomposition and carbon storage of hardwood and softwood branches in laboratory-scale landfills. *Sci Total Environ* 557–558:355–362
- Kaza S, Yao L, Bhada-Tata P, Van Woerden F (2018) What a waste 2.0: a global snapshot of solid waste management to 2050. Overview booklet. World Bank, Washington, DC