

Estimating methane emission from solid waste landfill using various different methods

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Abstract. Solid waste management is one of biggest problems for big cities in Indonesia. Currently, open dumping method is applied for managing the waste generated and produces methane emission as one of potential global warming gasses. This paper examined the methane that generated by Benowo landfill in Surabaya and Antang landfill in Makassar. Four methods were applied, namely IPCC default method, zero order, landGEM, and Order decay method. The result showed that methane emission quantity generated by these two landfills was significantly influenced by two local climate parameters: temperature and rainfall intensity. In addition, the analysis method used was also contributing to the volume of methane emission emitted.

1. Introduction

As a developing country, Indonesia has a main problem in waste management particularly municipal organic waste. This typical waste is predicted to increase in yearly basis align with the population growth. The Indonesian Statistical Bureau (2015) revealed that Surabaya city with 2,870,200 inhabitants generated 539,342.25 tons of waste while Makassar city with 1,369,606 populations generated 1,632,045 ton of waste. These figures indicate that the ratio between waste and residents in Surabaya and Makassar cities were 0.19 ton/person and 1.19 ton/person respectively and it increases every year. The waste management issues can be found globally particularly in Southeast Asia [1]. In addition, [2] and [3] noted that the waste management study is the most crucial issue that should be considered.

Methane (CH_4), Hydrogen Sulphide (H_2S), and Carbon dioxide (CO_2) are three main gasses that generated from organic waste landfill. These gasses contribute to the global warming and should be managed properly. There are three tools that can be used to calculate those gasses emissions from landfill operations, namely IPCC, CLEEN Model, and Land GEM [4, 5]. Zero and order-decay method are used as the basic reference.

The aim of this study is to calculate the Greenhouse Gasses (GHG) emission that generated by two landfills in Indonesia, namely Benowo landfill in Surabaya and Antang landfill in Makassar. Four methods that used are as follows: zero order, IPCC method and First Order, LandGEM Software.

2. Materials and methodology

2.1. The landfill site

Two landfills in Indonesia were investigated in this paper. One is located in Surabaya and another one



is located in Makassar. Both of the landfills are managed the huge amount of municipal waste. Therefore, these two landfills are suitable to be used as a case study to determine and evaluate the feasibility of landfill energy projects.

2.1.1. Benowo Landfill (LF 1). LF 1 is ± 37.4 hectares in size and its final height will be between 5 – 12 m. The Benowo landfill has been operating since November 2001 and manages all wastes generated by Surabaya city. The LF1 closure plan is predicted on 2030. The total municipal waste that managed by LF1 is approximately 539 thousand tons per year as shown in table 1.

Table 1. Quantity of solid waste disposed into Benowo landfill.

Year	Quantity (ton/year)
2003	204,000.00
2004	335,618.50
2005	467,237.00
2006	598,855.50
2007	540,200.00
2008	459,425.50
2009	448,741.95
2010	463,779.05
2011	478,816.14
2012	493,853.24
2013	508,890.33
2014	531,403.50
2015	539,342.25

Source: central bureau of statistic, Indonesia

2.1.2. Antang Landfill (LF 2). LF 2 is ± 14.3 hectares in size and its final height will be between 5 – 12 m. Most of the areas have been capped and almost reach its final design capacity. Antang landfill was operated in 1993 and covers all wastes generated by Makassar city. The LF2 closure stage is planned on 2032 with total wastes disposed on 2015 were 1.6 million tons as shown in table 2.

Table 2. Quantity of solid waste disposed into Antang Landfill.

Year	Quantity (ton)
2003	1,027,495
2004	1,077,874
2005	1,128,254
2006	1,178,633
2007	1,229,012
2008	1,279,391
2009	1,329,770
2010	1,380,149
2011	1,432,085
2012	1,480,907
2013	1,531,287
2014	1,581,666
2015	1,632,045

Source: central bureau of statistic, Indonesia

2.2. Landfill gas generation model

Two methods were used in this study for estimating the emission rates of total landfill gas generated by municipal solid waste landfill. These methods are Landfill Gas Emission Model (LandGEM)

software and Default Model that developed by The United State Environmental Protection Agency (US EPA) and IPCC respectively. The model determines the mass of methane generated by using the methane generation capacity and the mass of dumped waste. Table 3 shows the comparison of CHG emission estimation methods.

Table 3. Comparison of CHG emission estimation methods.

Features	Methodology	
Reaction Kinetics	Default method zero order	LandGEM first order
Model equation	$QCH_4 = \left\{ \frac{MSW_t \times MSW_f \times MCF \times DOC \times DOC_f \times F \times x}{\left(\frac{16}{12} - R\right) \cdot (1 - OX)} \right\}$ <p>Where QCH₄: annual CH₄ generation (Gg/yr.); MSWT: total MSW generated (Gg/yr); MSW_f: Fraction of MSW disposed at SWDS (generally 80%); MCF: CH₄ correction factor (fraction); DOC: Degradable organic carbon[Fraction (CGgMSW)]; DOC_f: Fraction DOC dissimilated; F: Fraction by volume of CH₄ in Landfill gas; R: recovered CH₄ (Gg/yr.); OX: oxidation factor (fraction).</p>	$QCH_4 = \sum_{i=1}^n \sum_{j=0.1}^n K L_o \left(\frac{M_i}{10}\right) e^{-KT_{ij}}$ <p>Where QCH₄: annual CH₄ generation (mg/yr); i=1 year time increment; n: (year of the calculation) – (initial year of waste acceptance); j: 0.1 year time increment; k: CH₄ generation rate(year-1); Lo: potential CH₄ generation capacity (m3/Mg); Mi: mass of waste accepted in the ith year (Mg); tij: age of the Jth section of waste mass Mi accepted in the i-th year.</p>

The study initiated by EPA defines the electricity generation potential from landfill between 75-85% of the total methane produced. With the calorific value of methane is 4.5 kWh/year then the formula to estimate the potential electricity as shown in equation (1).

$$\text{Electricity per year} = \frac{CH_4}{\text{year}} \cdot 75\% \cdot 4.5kWh \quad (1)$$

The CH₄ generation rate constant (K) is the rate of waste decay and It can be calculated by using the equation (2).

$$K = 3.2 \cdot 10^{-5}(R) + 0.01 \quad (2)$$

Where R is an average annual precipitation in mm. Value of K for Benowo and Antang landfills are presented in table 4 and some assumptions made for Benowo and Antang landfills are shown in table 5.

Table 4. K values for Benowo and Antang landfills.

Location	Average precipitation (mm/year)	K (year ⁻¹)
Benowo	141.1 mm	0.01
Antang	22,186.0 mm	0.08

Table 5. Assumption made for Benowo and Antang landfills.

Model parameter	Benowo Landfill		Antang Landfill	
	IPCC Default Method	LandGEM Method	IPCC Default Method	LandGEM Method
Methane Correction factor (MCF)	0.4	-	0.4	-
Fraction of CH ₄ in landfill gas (F)	0.5	0.5	0.5	0.5

Model parameter	Benowo Landfill		Antang Landfill	
	IPCC Default Method	LandGEM Method	IPCC Default Method	LandGEM Method
CH ₄ recovery (R)	0	-	0	-
Oxidation Factor (OX)	0	-	0	-
The CH ₄ generation rate constant (K) (year-1)	-	0.01	-	0.08
CH ₄ Generation potential (L ₀) (m ³ /mg)	-	170 (arid area)	-	170

3. Result and discussion

Based on the characteristics, Benowo landfill is located in arid area with the low annual precipitation and high temperature as presented in table 6. These two parameters resulted in the L₀ difference of Antang and Benowo landfills. Therefore, the data analysis used different reference LandGEM where Antang landfill use CAA Conventional and Benowo landfill uses CAA Arid Area.

Table 6. Operational parameters of Benowo and Antang Landfills, Indonesia.

Features	Detail	
	Benowo	Antang
Location: Latitude	7°13'9, 70'' S 112°37'52.18 T	5°10'36.02'' S 119°29'25,35'' T
Longitude		
Year of start	2001	1993
Year of closure	2032	2030
Area (Ha)	37.4	14.3
Annual precipitation	141.1 mm	2186 mm
Temperature (c)	35	27

In this study, the CH₄ emission calculation for Antang and Benowo Landfills showed the differences result between IPCC Default method and LandGem. The result generated by IPCC was 20 times higher than LandGEM. The similar result was also shown in [1], when the author calculated CH₄ emission from open dump site in Kapur, India. The author found that the difference due to the elimination of temperature and rainfall fall parameters from the analysis. However, this study was considering use the higher result of CH₄ Produced to manage the risks that might occurred properly.

CH₄ emission generated by Benowo Landfill using LandGEM showed that it increased in yearly bases until the landfill closure period. In addition, the analysis indicated that the estimation was two times higher compared to IPCC calculation. The result also showed that methane emission generated by landfill in arid area was higher compared to landfill in other areas. The calculation of methane emission using various methods is presented in table 7 and figure 1 and figure 2.

Table 7. CH₄ emission from Benowo and Antang Landfills using various models.

Year	Waste quantity (mg/year)		Benowo IPCC(Default Method)	Antang IPCC (Default Method)	Benowo Land GEM	Antang Land GEM
	Benowo	Antang				
2004	305,108	979,886	9,021.12	318,996.40	458.6	5,180
2005	424,761	1,025,685	12,558.91	304,215.70	1,135.0	10,360
2006	544,414	1,071,484	16,914.97	318,434.40	2,068.0	15,540
2007	491,091	1,117,284	15,573.15	332,653.20	3,251.0	20,730

Year	Waste quantity (mg/year)		Benowo	Antang	Benowo	Antang
	Benowo	Antang	IPCC(Default Method)	IPCC (Default Method)	Land GEM	Land GEM
2008	417,660	1,163,083	13,244.54	346,872.30	4,290.0	25,910
2009	407,947	1,208,882	12,936.55	361,091.10	5,144.0	31,100
2010	421,617	1,254,681	12,150.29	29,815.42	5,959.0	36,280
2011	435,287	1,301,895	12,544.24	31,365.01	6789.0	41,470
2012	448,957	1,346,279	12,938.19	32,777.35	7,633.0	46,670
2013	462,628	1,392,079	13,332.13	74,907.72	8,491.0	51,860
2014	483,094	1,437,878	13,921.94	77,456.05	9,363.0	57,050
2015	490,311	1,483,677	14,129.93	80,004.33	10,260.0	62,240
2016	489,784	1,454,126	14,114.73	82,552.62	11,160.0	67,430
2017	493,163	1,470,557	14,212.12	242,725.10	12,040.0	72,210
2018	496,566	1,487,175	14,310.18	409,113.10	12,910.0	76,840
2019	499,992	1,503,980	14,408.93	579,230.70	13,770.0	81,340
2020	503,442	1,520,975	14,508.35	753,140.60	14,620.0	85,710
2021	506,916	1,538,162	14,608.45	930,906.90	15,470.0	89,960
2022	510,414	1,555,544	14,709.25	1,112,595.00	16,300.0	94,110
2023	513,936	1,573,121	14,810.75	1,298,270.00	17,130.0	98,140
2024	517,482	1,590,897	14,912.94	1,487,999.00	17,940.0	102,100
2025	521,052	1,608,875	15,015.84	1,681,850.00	18,750.0	105,900
2026	524,648	1,627,055	15,119.45	1,879,893.00	19,550.0	109,700
2027	528,268	1,645,440	15,223.77	2,082,196.00	20,340.0	113,400
2028	531,913	1,664,034	15,328.82	2,288,830.00	21,130.0	116,900
2029	535,583	1,682,837	15,434.59	2,499,870.00	21,900.0	120,500
2030	539,279	1,701,854	15,541.08	2,715,386.00	22,670.0	123,900
2031	543,000	-	15,648.32	-	23,440.0	-
2032	546,746	-	15,756.29	-	24,190.0	-

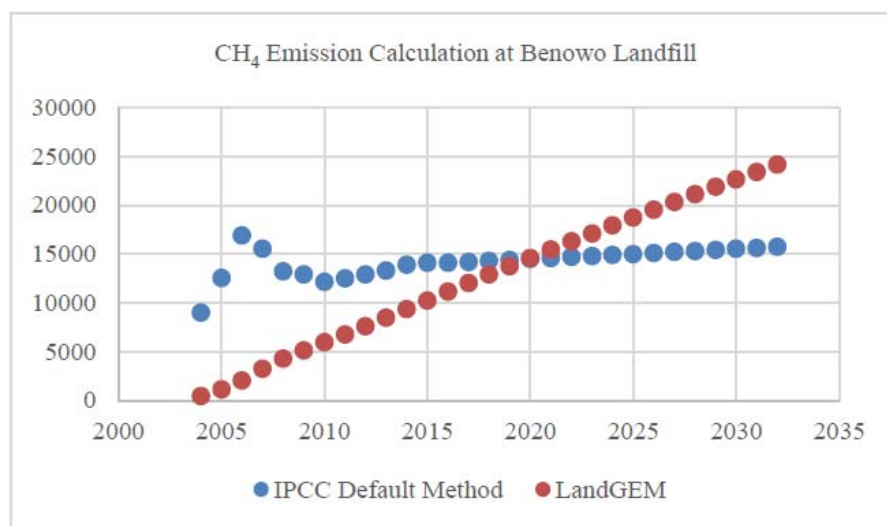


Figure 1. CH₄ emission calculation at Benowo landfill.

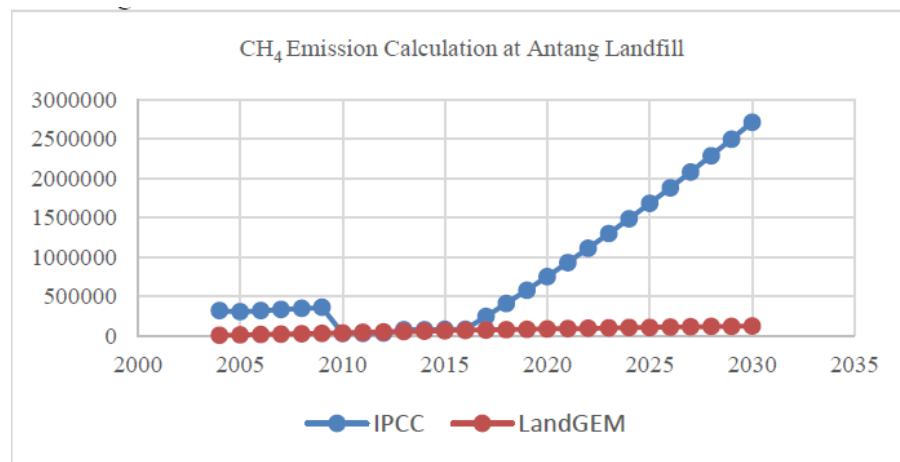


Figure 2. CH₄ emission calculation at Antang landfill.

Waste management is required to minimize the CH₄ emission environmental impact. Application of proper waste management system including sanitary landfill method would assist the CH₄ emission reduction from landfill area.

4. Conclusions

The study shows that temperature and rainfall intensity are two main parameters for estimating CH₄ emission from landfill. These two parameters resulted in high methane emission emitted by Antang and Benowo landfill. In addition, the calculation method used is also contributing to the analysis results. IPCC and LandGEM method generate different results in estimating CH₄ emission from Benowo and Antang landfill. The difference occurred due to temperature and rainfall intensity variation.

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