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 gases. 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 tons 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 (CH₄), Hydrogen Sulphide (H₂S), and Carbon dioxide (CO₂) 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.

| 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

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

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.

| 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

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

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         | \( Q_{CH_4} = \left( \frac{MSW_i \times MSW_f \times MCF \times DOC \times DOC_f \times F \times 16}{12 - R} \times (1 - 0.5) \right) \) | \( Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{n} K_{Lo} \left( \frac{M_i}{10} \right) e^{-KT_{ij}} \) |

Where \( Q_{CH_4} \): annual \( CH_4 \) generation (Gg/yr.); MSWT: total MSW generated (Gg/yr); MSW\(_c\): Fraction of MSW disposed at SWDS (generally 80%); MCF: \( CH_4 \) correction factor (fraction); DOC: Degradable organic carbon\( (CGgMSW) \); DOC\(_c\): Fraction DOC dissimilated; F: Fraction by volume of \( CH_4 \) in Landfill gas; R: recovered \( CH_4 \) (Gg/yr.); OX: oxidation factor (fraction).

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).

\[
Electricity \ per \ year = \frac{CH_4 \, generation}{year} \times 75\% \times 4.5kWh
\] (1)

The \( CH_4 \) generation rate constant (K) is the rate of waste decay and It can be calculated by using the equation (2).

\[
K = 3.2 \times 10^{-5} (R) + 0.01
\] (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 CH4 in landfill gas (F) | 0.5 | 0.5 | 0.5 | 0.5 |
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 $L_0$ 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                  |
|---------------------------------|-------------------------|
| Location: Latitude              | 7°13’9.70” S           |
|                                 | 112°37’52.18 T          |
| Longitude                       |                        |
| Year of start                   | 2001                    |
| Year of closure                 | 2032                    |
| Area (Ha)                       | 37.4                    |
| Annual precipitation            | 141.1 mm                |
| Temperature (c)                 | 35                      |
|                                 | 5°10’36.02” S           |
|                                 | 119°29’25.35” T         |
|                                 | 2030                    |
|                                 | 14.3                    |
|                                 | 2186 mm                 |
|                                 | 27                      |

In this study, the $\text{CH}_4$ 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 $\text{CH}_4$ 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 $\text{CH}_4$ Produced to manage the risks that might occurred properly.

$\text{CH}_4$ 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. $\text{CH}_4$ emission from Benowo and Antang Landfills using various models.

| Year | Waste quantity (mg/year) | Benowo IPCC(Default Method) | Antang IPCC(Default Method) | Benowo LandGEM | Antang LandGEM |
|------|--------------------------|-----------------------------|-----------------------------|-----------------|----------------|
| 2004 | 305,108                  | 9,021.12                    | 318,996.40                  | 458.6           | 5,180          |
| 2005 | 424,761                  | 12,558.91                   | 304,215.70                  | 1,135.0         | 10,360         |
| 2006 | 544,414                  | 16,914.97                   | 318,434.40                  | 2,068.0         | 15,540         |
| 2007 | 491,091                  | 15,573.15                   | 332,653.20                  | 3,251.0         | 20,730         |
| Year  | Waste quantity (mg/year) | Benowo | Antang | IPCC(Default Method) | IPCC( Default Method) | Benowo | Antang | 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          | 6789.0                | 41,470 |
| 2011  | 435,287                  | 1,301,895 | 12,544.24 | 31,365.01          | 7,633.0               | 51,860 |
| 2012  | 448,957                  | 1,346,279 | 12,938.19 | 32,777.35          | 8,491.0               | 57,050 |
| 2013  | 462,628                  | 1,392,079 | 13,332.13 | 74,907.72          | 9,363.0               | 62,240 |
| 2014  | 483,094                  | 1,437,878 | 13,921.94 | 74,907.72          | 10,260.0              | 67,430 |
| 2015  | 490,311                  | 1,483,677 | 14,129.93 | 80,004.33          | 11,160.0              | 72,210 |
| 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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