Original Article

e-ISSN: 2581-0545 - https://journal.itera.ac.id/index.php/jsat/

Estimation of methane emission from Piyungan landfill using IPCC method

Received 9th June 2022
Accepted 3rd October 2022
Published 12th April 2023

Open Access

DOI: 10.35472/jsat.v7i1.953

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Abstract: One of the greenhouse gases that causes climate change is the emission of methane (CH_4) produced by landfills. The methane comes from the anaerobic decomposition of organic matter in the waste at the landfill. The purpose of this study is to estimate methane emissions at the Piyungan landfill, Bantul, Yogyakarta, from 2021 to 2025 using IPCC method. No similar work has been conducted so far, especially in the Piyungan landfill. The result shows that methane emissions produced at the Piyungan landfill in 2021 is 544.05 tons with a total waste generation of 549.49 tons/year and is dominated by 88% organic waste. Meanwhile from 20,786 tons of waste generated in 2025, the methane emissions are estimated to be 573.85 tons. To minimize the methane emission from Piyungan landfill, it is recommended mitigation and adaptation efforts, i.e., the 3R method (reduce, reuse, recycle), the composting of organic waste, the addition of gas ventilation pipes. The methane gas from the Piyungan landfill should be explored as alternative energy fuel in future work.

Keywords: *waste; methane; emission; landfill; IPCC method.*

Introduction

To encounter the problem of waste disposal in three cities, i.e., Sleman, Bantul, and Yogyakarta, the Province of D.I. Yogyakarta built Piyungan landfill located at Piyungan District, Bantul Regency. The site has area of 12.5 Ha of which 10 Ha is used as a landfill and 2.5 Ha is used as supporting facilities in the form of offices, workshops, weighbridges, and buffer zones [1]. An average of 450 ton a day of waste from those cities is disposed to the Piyungan landfill. The dominant type of waste is organic waste, which is approximately 72% of the total waste. However, another problem arises when the waste in the landfill does not manage and processed properly. It can generate methane (CH_4) gas and carbon dioxide (CO_2) gas. Typically, municipal solid waste can generate 50-60% CH_4 and 40-50% CO_2 [2-4]. Anaerobic decomposition of organic compound content of the waste produce CH_4 which is one of the greenhouse gases that contribute to climate change.

The generation of CH_4 from landfill can be affected by several factors, such as weather, population, type and composition of the waste, etc. Population growth and consumptive community patterns [5] are often cited as determinants of increasing waste production in urban areas and the lack of waste management. During 2019, the population growth rate in Yogyakarta was 1.15% and the amount of waste production was 644.69 tons/day [6]. Population growth is an important factor in determining the amount of waste generation. Therefore, it is necessary to take into account population projections for the next few years in an effort to prevent urban waste production. Meanwhile, the composition of the waste found in a landfill will affect the potential for methane emissions produced. In general, the higher the percentage of biodegradable organic waste, the higher the potential for methane emissions to be generated. The rate and composition of waste generation varies depending on the economic situation, industrial sector, waste management regulations and lifestyle.

There are several method in evaluating methane emission, including field experiment and mathematical modelling [7]. Field experiment technique for evaluating methane emission can be performed using a mobile tracer dispersion method. The method with either Fourier transform infrared spectroscopy (FTIR), using nitrous oxide as a tracer gas, or cavity ring-down spectrometry (CRDS), using acetylene as a tracer gas has been employed by Monster et al. [8] to quantify methane emission from several landfills in Denmark. A new approach in field experiment using a TDLAS (Tunable Diode Laser Absorption Spectroscopy) instrument is proposed by Zhu et al. [9].

Meanwhile, several mathematical models have been used in predicting methane emission from landfill. Das et al. [10] used four different models, i.e. First Order model, Multi-phase model, LandGEM model, and EPER Model to estimated landfill gas generation from municipal solid waste Indian cities. LandGeM model includes two parameters, the methane production potential and the first-order decay rate constant [11]. Meanwhile, Mohsen and Abbassi [12] used fuzzy logic model to predict greenhouse gas emissions from Ontario's solid waste landfills. Another common model used to estimate CH_4 emission is Inter Governmental Panel on Climate Change (IPCC) model. The IPCC model is based on a First Order Decay (FOD) model that assumes biodegradation kinetics depending on the type of wastes [13]. The IPCC model is integrated with (Long-range Energy Alternative Planning (LEAP) model by Nojedehi et al. [14]. The IPCC predicted the methane flow rate emission and LEAP model estimated energy and non-energy emission.

Since the methane emission from landfill contributes to global warming, it is important to estimate methane emission generated by landfill in the next few years in order to obtain proper method to manage the waste in landfill. Thus, the estimation of methane emission from Piyungan landfill during 2021 - 2025 is performed by field mining data and mathematical model using IPCC 2006 method in the present work. The IPCC method is based on population growth in Sleman, Bantul, and Yogyakarta, waste generation rate, and waste composition in the Piyungan landfill.

Novelty statement:

The work of investigating methane emission from the Piyungan landfill from 2021 to 2025 by field mining data and mathematical model using IPCC 2006. No similar work has been reported so far, especially similar work performed at the Piyungan landfill in Yogyakarta

Method

Field Experiment

The field experiment aims to collect primary and secondary population data in Sleman, Bantul, and Yogyakarta cities and the waste generation rate of the landfill. The population data of those three districts in Yogyakarta were obtained from the Central Bureau of Statistics (*Badan Pusat Statistik*) Yogyakarta Province. Meanwhile, the waste generation rate data were obtained from Piyungan landfill which is an open damping landfill

IPCC Modelling

Estimation of population growth

The population of the cities from 2021 to 2025 were estimated based on the population in those cities in 2020 using the arithmetic method and calculated using Eq. (1). IPCC method is a method which is issued by International Panel on Climate Change (IPCC). The method has been used around the globe due to its simple calculation procedure.

$$P_n = P_o(1 + rt) \tag{1}$$

Pn is the population of the projected year, Po is the population of the baseline year, r is population growth, and t is the projection duration

Calculation of waste volume

According to SNI 19-3964-1994 standard, the volume of waste in the Piyungan landfill was projected by counting the number of dump trucks that dispose the waste to the landfill for 8 consecutive days. After determining the volume of the waste, the density of the waste and waste generation rate were calculated based on the SNI 19-3964-1994 standard. To obtain the density, the wastes were mixed homogenously and loaded into the container box having dimension of 0.5 m x 1.0 m x 1.0 m. The fulfilled container was stomped to the ground three times from height of 20 cm. The density was calculated using Eq. (2). Furthermore, the waste generation rate can be obtained using Eq. (3). Once the volume, the density, and generation rate were obtained, the waste generation was then estimated using Eq. (4).

$$\rho = \frac{m}{V_b} \tag{2}$$

where ρ is the density of the waste (kg/m^3), m is the mass of the waste in the container box (kg), and Vb is the volume of the container box (m^3)

$$\dot{m} = \frac{\bar{V}}{P_0} \times \rho \tag{3}$$

where $\dot{m}$ is the rate of waste generation, $\bar{V}$ is the average volume of the waste in the landfills (m^3), Po is the population baseline (person)

$$m_n = P_n \times \dot{m} \tag{4}$$

where m_n is the waste generation in n year, P_n is the population of n year (person)

Analysis of waste composition

After determining the rate of waste generation, then the calculation of the composition of the waste was performed. The first stage was done by sorting the waste samples based on the type of waste, and there are six types of organic waste according to the IPCC (2006) namely, food waste, leaves, wood, paper, textiles, and nappies. After that, the

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measurement of the weight percentage of waste per component was carried out with Eq. (5)

$$x_1 = \frac{m_{x1}}{\sum m} \times 100\% \quad (5)$$

where x_1 is the weight percentage of x component (%), m_{xi} is the mass of x component (kg), the total mass of the waste (kg)

Estimation of methane emission

Estimation of CH_4 emission at Piyungan landfill was based on waste composition, waste volume, degradable organic carbon (DOC), fraction of DOC that can decompose (DOC_f), methane correction factor for aerobic decomposition in the year of deposition (MCF), a fraction of methane in generated landfill gas (F) according to IPCC. According to the IPPC method 2006, Eq. (6) and Eq. (7) were used to estimate total degradable waste and the potential of methane emission [15, 16] at the Piyungan landfill

$$DDOC_m = DOC \times DOC_f \times MCF \times W \quad (6)$$

where DDOCm is the part of the organic carbon that will degrade under the anaerobic conditions in SWDS is the mass of fixed carbon (ton), DOC is the degradable organic carbon in a year (Gg C/Gg waste), DOC_f is the rafction of degradable organic carbon (0.5 for Indonesia), and MCF is the methane correction factor for aerobic decomposition in the year (ton), and W is the mass of waste in the landfills (ton)

$$L_o = \frac{16}{12} \times DDOC_m \times F \quad (7)$$

where Lo is the potential of methane emission (ton/year), a constant 16/12 is indicated by the ratio between methane molecular weight and carbon atomic weight, and F is the fraction of methane in landfill gas produced.

Generally, the higher the percentage of biodegradable organic waste, the higher the potential for CH_4 emissions to be generated. In the present work, sampling was conducted on 15-22 September 2020, during the dry season. To determine the composition of the waste, it is done manually by separating the waste contained in the sampling box according to its type/composition, which will then be weighed by the weight of each waste based on its type/composition

Results And Discussion

Figure 1 shows a projection of the population of Bantul, Slemen, and Yogyakarta in the next five years (2021-2025) by the arithmetic method. Based on the results of the projection using the arithmetic method, it can be seen that Sleman city will have the largest population in the year 2025, such that almost 1.3 million. Meanwhile, Yogyakarta city will have the lowest population of about 460,792 in 2025. Total population of those three cities will reach 3.0 million in 2025

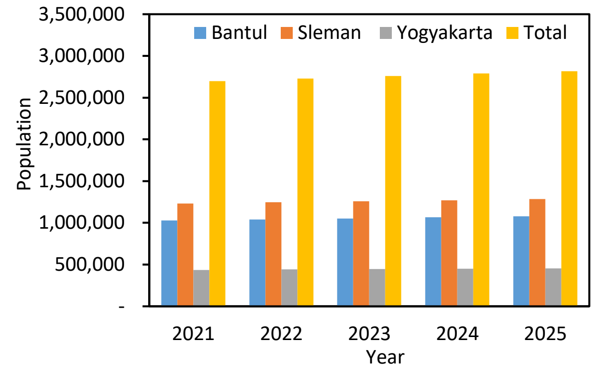

Figure 1. Projection of population of Sleman, Bantul, and Yogyakarta in 2021-2025.

The disposal rates for the landfill from those cities are given in Figure 2. The data were taken from the weighbridge to the landfills for eight days. From Figure 2, it can be seen a dynamic graph, where the amount of waste varies every day, the highest amount of waste is generated on the 2nd day (769,962 m^3) and the lowest on the 6th day (234,906 m^3).

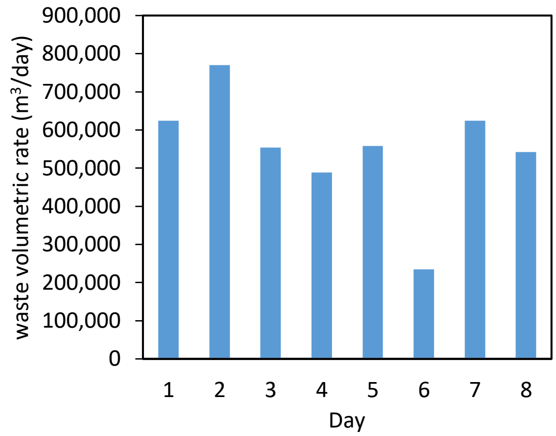

Figure 2. Waste generation rate to the landfill.

Figure 3 presents the result of the waste generation rate from the city of Sleman, Bantul, and Yogyakarta. The result shows that the rate of waste generation from 2021 to 2025 increased significantly. It can be seen from the graph, the rate of waste generation was about 19,900 tons in 2021 and will increase to about 20,800 tons in 2025.

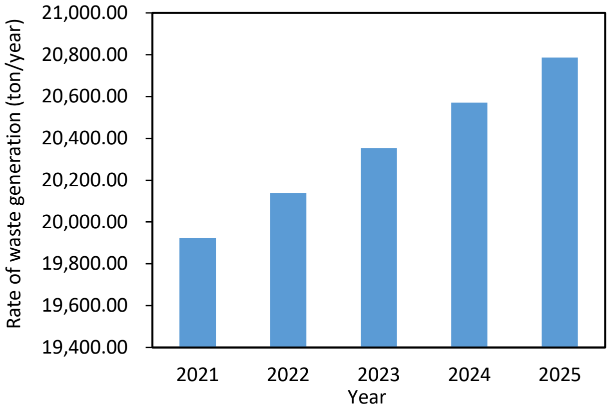

Figure 3. Estimation of rate of waste generation in 2021-2025.

The composition of waste in the landfill affects the generation of CH_4 emissions. Generally, the higher the percentage of biodegradable organic waste, the higher the potential for CH_4 emissions to be generated. In the present work, sampling was carried out on 15-22 September 2020, during the dry season. To determine the composition of the waste, it is done manually by separating the waste contained in the sampling box according to its type/composition, which will then be weighed by the weight of each waste based on its type/composition. The percentage composition of waste in the Piyungan landfill is shown in Figure 4. It is obtained that the waste in the Piyungan landfill mostly consists of food garbage and leaves, which are 54.36% and 20%, respectively. The rest of 25.64% are shared by wood, straw, plastics, rubber, nappies, etc. Typically, organic waste includes food waste, leaves, wood, paper, textiles, and nappies.

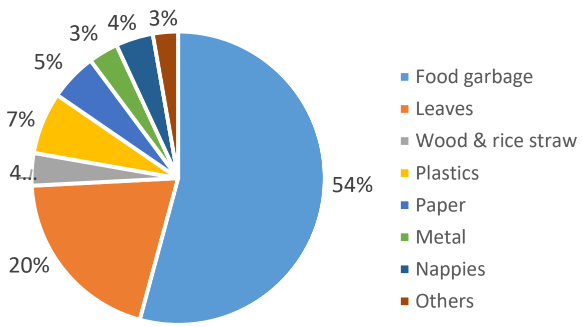

Figure 4. Typical waste composition of the Piyungan landfill.

Estimation of methane emissions in the Piyungan landfill is based on the percentage of waste composition, waste generation data, and default data that have been determined by the IPCC (Intergovernmental Panel of Climate Change), namely, DOC (Degradable organic carbon) data, DOC_f (Fraction of DOC can decompose), MCF (CH_4 Correction factor for aerobic decomposition in the year of deposition), and F (Fraction of CH_4 in generated landfill gas). Table 1 shows the IPCC default values. Meanwhile, the values of DOCf, MCF, and F obtained are 0.5

Table 1. IPCC default values for DOC.

Composition	**DOC (% dry weight)**	
	Default	Range
Food garbage	0.15	0.08-0.20
Leaves	0.20	0.18-0.22
Paper	0.40	0.36-0.45
Wood & Straw	0.43	0.39-0.46
Textile	0.24	0.20-0.40
Nappies	0.24	0.18-0.32

Figure 5 shows the estimation of CH_4 emissions in the Piyungan landfill from 2021-2025. It can be seen the CH_4 emissions will reach 573.85 tons in 2025. Meanwhile, Sasmita et al [17] predicted that 1.331.487 m^3/year of methane could be generated from Muara Fajar landfill Pekanbaru. The CH_4 emissions from 2021 to 2025 will increase by an average of 5.96 tons/year. The estimated CH_4 emission at the Piyungan landfill increases from year to year. The condition of the Piyungan landfill at the time of the research can be said to be wet because its composition is 88% in the form of easily biodegradable waste. Theoretically, biodegradable waste in the Piyungan TPA has the potential to produce large amounts of CH_4. From the estimation values of the CH_4 emission from 2021-2025, it is recommended that the need to implement and socialize 3R techniques (reduce, reuse and recycle) to reduce the volume of waste disposed of in the landfill, optimize composting activities both in sources and at the landfill, adding gas ventilation pipes in the waste heap, and changing the waste handling system at the landfill. These efforts are expected to be able to control the CH4 emissions better. For the future work, it is a potential to capture the CH_4 emission and convert it into useful source of alternative fuel. This work is very important not only for people in those cities to manage their domestic waste but also for the local government of Yogyakarta Province. The result of the work can be used as a reference for making regulation of waste management and methane mitigation at Piyungan landfills

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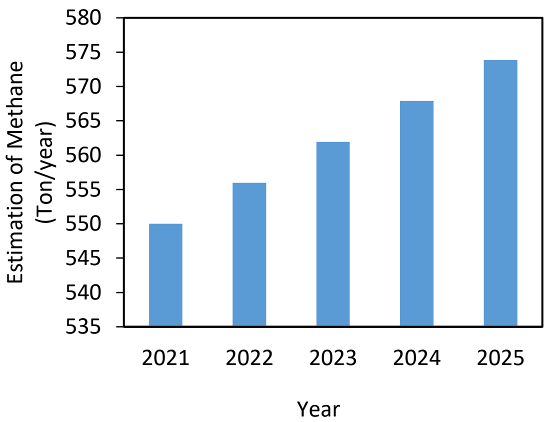

Figure 5. Estimation of CH_4 emission at Piyungan landfill in 2021-2025.

Conclusions

The prediction of the CH_4 emission at the Piyungan landfill has been performed. It can be concluded that:

1. The amount of waste generated at the Piyungan landfill in 2021 is 19,706.73 tons/year. The estimation of the waste generation in 2025 is 20,786.09 tons/year
2. The percentage of waste composition in the Piyungan landfill is dominated by organic waste (biodegradable), which is 88.17% organic waste consisting of food waste 54.36%, leaves 20.02%, wood 3.59%, paper 5.25%, textiles 0.81% and nappies 4.14%,
3. The potential value of methane emissions produced at the Piyungan landfill in 2020 is 544.05 tons/year. The CH4 emission at the Piyungan landfill in 2025 is estimated will be 573.85 tons/year
4. Mitigation and adaptation efforts that can be applied to the current condition of the Piyungan TPA are by implementing the 3R (reduce, reuse, recycle), application of the use of organic waste in the form of composting, adding gas ventilation pipes in the waste body, utilizing the gas produced such as conversion methane gas into fuel.

Conflicts of interest

There are no conflicts of interest in the manuscript.

Acknowledgements

The authors thank Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia for the financial support for the publication of the work through the scheme of Program Kompetisi Kampus Merdeka (PKKM) 2021.

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