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Estimation Potential Of Methana Gas From Puwatu Municipal Solid Waste Landfill, Indonesia

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Abstract. Methane gas produced from municipal solid waste landfill has excellent energy potential if managed with the right technology. This study aims to estimate the amount of methane emissions from Puuwatu landfill in Kota Kendari, Indonesia using LandGEM V303 software. The LandGEM model used is based input data on the year landfill was opened and received waste, the year landfill was closed, and the potential for methane production. Total methane production in 2011 reached 8.3×10^2 (Mg/year), the first year after receipt of waste by landfill while the maximum methane production rate occurred during 2027, indicating a production peak of 1.44×10^4 (Mg/year). The results of this study can be used for the design and operation of methane collection and control of greenhouse gas emissions.

1 Introduction

Increased greenhouse gas (GHG) emissions have an impact on global warming and climate change. The Intergovernmental Panel on Climate Change predicts global temperatures will increase by 1.5°C in 2021 to 2040 [1]. Rising global temperatures will have an impact on melting polar ice caps and rising sea levels around the world. Environmental risks from rising sea levels include, coastal settlement infrastructure will be damaged, and lowland ecosystems will sink or even disappear. GHG emissions must be reduced through measures to control global warming and climate change. It was within this framework that in 2015 the Paris Agreement was agreed upon and signed by 197 members of the United Nations Framework Convention on Climate Change (UNFCCC) with the hope of reducing global warming to 2^0C [2]. Indonesia is one of the countries participating in this activity [3].

Indonesia is a developing country, its territory consists of small islands that are vulnerable to environmental risks from climate change. The Indonesian government is very serious

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about the issue of global warming and climate change by targeting emission reductions. Indonesia's national emission reduction target is 29% through its own efforts and 41% with international cooperation in 2030 [4]. GHG emissions come from various anthropogenic activities, which are grouped into various sectors, namely the energy sector, industrial sector, agriculture and forestry and other land use (AFOLU), and waste sector. GHG emission data in Indonesia for 2022, energy sector is 584,284 Gg CO2e, industrial process sector is 57,194 Gg CO_2e, agricultural sector is 98,703 Gg CO_2e, forestry sector and peatland fires is 184,435 Gg CO2e, and the waste sector is 126,797 Gg CO2e [5]. The waste and solid waste sector contributes the third largest GHG emissions after the forestry and energy sectors.

The waste sector cannot be underestimated because this sector can increase the global warming potential (GWP). When the practice of burning or open burning will release short-lived climate pollutants (SLCP), such as black carbon (BC) and methane (CH_4) which have a higher global warming potential than CO_2 [6]; [7]. Kaza et al.,[8] found that 5% of global GHG emissions are due to poor solid waste management. The generation of municipal waste (MSW) is estimated at 3.4 billion tons in 2050. This amount of waste generation becomes an environmental threat if it is accompanied by poor waste management such as a lack of 3R practices (reduce, reuse, recycle), inefficient waste transportation and collection services, and improper waste closure systems.

Kota Kendari is a medium city, located on the southeastern coast of Sulawesi Island, Indonesia. In general, as the city, it is often faced with urban environmental problems, such as population, sanitation, waste and others. The population of Kendari City is 356,747 persons in 2022. It is predicted that the population of the city will reach 415,448 people with waste generation per capita of 298,933 kg/person/day in 2030 (BPS Kota Kendari, 2022a). Currently, urban waste handling has only reached 56.7% of the national target of 70% [9]. The final waste processing location in Kendari City is located at the Puuwatu landfill, Puuwatu District, Kendari City. This landfill has been operating since 2002, initially using an open dumping system. However, since 2011 the operating system has become a controlled landfill. The waste that enters the Puuwatu landfill ranges from ± 180 tons per day.

During waste collection activities at the landfill, biological and chemical processes will occur by microbes anaerobically which will produce landfill gas (LFG). The main components of this LFG include about 40-50% carbon dioxide and about 50-60% methane [10]. Carbon dioxide and methane produced from LFG actively contribute to emitting GHG into the atmosphere. Methane gas has the potential to be 21 times greater than carbon dioxide in its contribution to global warming. Even though the waste is buried in the ground, a small portion of this gas will still evaporate into the atmosphere. There have been many studies that predict the amount of gas production from urban waste landfills. Various models have been devised to calculate GHG emissions, oxidation, and landfill LFG production. Measuring the predicted amount of methane gas emissions from landfills in Indonesia can assist in reducing global greenhouse gas (GHG) emissions. Therefore this study aims to describe gas emissions at the Puuwatu Landfill, Kendari City through the Land GEM model. Product estimation results The methane and carbon dioxide actions in the Puuwatu landfill can make a broad contribution to the development of GHG mitigation efforts, especially in archipelagic and developing countries such as Indonesia and on a global scale.

2 Materials and Methods

2.1 Study Area

This research is a descriptive cross sectional method using LandGEM Version 3.02 software issued by the US EPA. One of the good enough software to estimate the GHG potential of landfill [11]; [12]. This software is used to estimate emission production at the Puuwatu landfill, Kota Kendari with several adjustments for tropical environments. Puuwatu landfill is located at coordinates 3°59'22.4"S 122°28'07.8"E. Located in the administrative area of Puuwatu District, Kota Kendari, Southeast Sulawesi, Indonesia. In addition, in terms of climate elements, the average air temperature is 27.10C, the average humidity is 86.6%, the average wind speed is 0.8 m/s, the average air pressure is 1004.9 mb, and the rainfall 188.9 mm3 [13]. The Puuwatu landfill has a land area of 18 hectares and has been operating since 2002. Initially, the operation used an open dumping system and since 2008 the operating system has changed to a controlled landfill. Garbage that enters reaches an average of 180 tons/day.

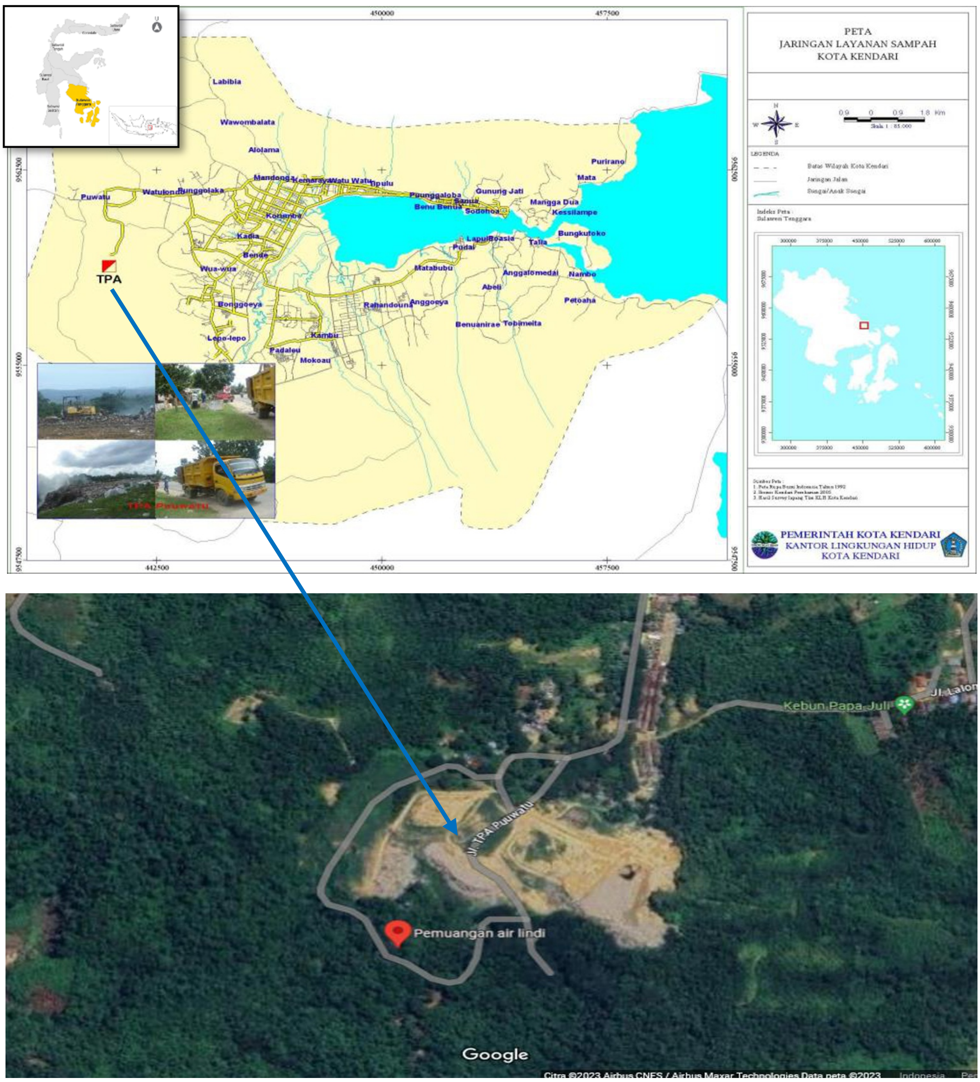

Fig. 1. Sudi Area-Puuwatu landfill, Kota Kendari, Indonesia

2.2 Data Colection

Data on the annual growth conditions for the Puwatu landfill waste were collected through a literature of the Puwatu landfill master plan and previous studies. In addition, the required data including potential methane production capacity, constant methane value, and content (% volume) are entered into the software and finally methane emissions are calculated. Waste generation is closely related to population growth in a city. According to [13] the population of Kota Kendari in 2002 was 221,881 people, and in 2022 the population of Kota Kendari has reached 356,747 people. There was an increase of 68.3% over the last 10 years. Urbanization, geographical characteristics, economic development, politics, socio-culture have allegedly influenced the population growth.

Waste generation in Kota Kendari has increased every year so that the waste storage area (landfill) at the Puuwatu landfill at one time experienced over capacity (over capacity). Increasing the area or finding a new location for the final waste processing site is the concern of the Kota Kendari Government. The amount of waste that enters the landfill fluctuates in certain months. This is related to the amount of waste transported by the garbage trucks serving the entire administrative area of Kota Kendari. In addition, 3R practices have not been implemented at the waste source level. Angriani and Suyuti [14] reports that the amount of waste composition in Kota Kendari is dominated by organic waste. The composition of the amount of waste is food waste 56.5%, diapers waste 15.1%, garden waste 6.5%, wood waste 6%, plastic waste 5%, paper/cardboard waste 4.1%, metal waste 2.4%, others 1.9%; rubber waste, 1.1% leather waste, 0.9% fabric waste and 0.6% glass waste. Judging from the composition of the waste at the Puuwatu landfill, the opportunity to turn it into energy potential is very possible.

2.3 LandGEM Model

This research is a descriptive cross-sectional study using Land GEM Version 3.02 software issued by the US EPA. One of the good enough software to estimate the GHG potential of landfill [11]; [12]. This software is used to estimate emission production at the Puuwatu landfill, Kendari City with several adjustments for tropical environments. Puuwatu landfill is located at coordinates 3°59'22.4"S 122°28'07.8"E. Located in the administrative area of Puuwatu District, Kota Kendari, Southeast Sulawesi, Indonesia. In addition, in terms of climate elements, the average air temperature is 27.1^0C, the average humidity is 86.6%, the average wind speed is 0.8 m/s, the average air pressure is 1004.9 mb, and the rainfall 188.9 mm^3 [13]. The Puuwatu landfill has a land area of 18 hectares and has been operating since 2002. Initially, the operation used an open dumping system and since 2011 the operating system has changed to a controlled landfill. Garbage that enters reaches an average of 180 tons / day.

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

Where Q_{CH4} is the amount of annual methane generation in that year ($m_{CH4}{}^3$/year); i is one year increment; n is defined as (counting year)-(starting year of receiving trash). Moreover, j is a 0.1 year time increment; k is the methane production rate ($year^{-1}$); L_o is the potential methane production capacity (m^3/Mg); M_i is the mass of waste received in year (Mg); tij is the age of the jth sector of the waste mass, Mi received in year i_{th} (decimal year, i.e. 3.2 years). Also in this study, the model parameters from user input are k = 0.050 $Years^{-1}$, L_o = 170 m^3/Mg, and methane content is 50% by volume. This is managed by two main factors, namely the rate of decomposition (k) and the potential capacity of methane (L_o) from landfill waste [15]. The potential for methane from waste depends on the amount of waste that can be decomposed, the degree of separation, the level of microbial use, volatile solids, climatic conditions such as humidity and temperature [16]; [17]. This model was made based on the climatic conditions and waste specifications in the United States [18]. The value of k determines the methane formation rate for the waste mass in the landfill. The parameters that affect the value of k are: (i) the availability of nutrients from the microorganisms that break down trash to produce carbon dioxide and methane; (ii) the pH of the waste mass; (iii) the moisture content of the waste mass; and (iv) the temperature of the waste mass. [19]. For the evaluation of Lo, the methane yield of a single waste component was taken from the d or default model of the software and literature on waste generated in the United States due to the lack of data regarding the characteristics of municipal solid waste in Kendari City. In this study, according to Table 2 based on LandGEM software data, the default values of k and Lo were used to be 0.05 year^{-1} and 170 m^3/Mg for the Puuwatu landfill, respectively. Even though the content of organic matter (food waste) is high with a weight percentage of 76.6%, the k value could be higher at the Puuwatu landfill but is considered the same as the default value. Characteristics of the model parameters for running LandGEM were adopted from Alexander et al. [19].

3 Results and Discussion

Data from the technical management planning report for landfill Puuwatu [20] shows an increase in the volume of incoming waste from year to year. The quantity of waste processed at landfill Puuwatu, Kendari City reached 149,878 Mg in 2011 and reached 308,580 Mg in 2027. This shows a rapid increase (106%) in urban waste production in Kendari City within 16 years of operation. Of course it is related to population growth, industrial area growth and commercial area growth, as well as people's habits. Estimation of methane emissions using LandGEM is a practical method that is adapted to consider the conditions of landfill management and waste composition at the time of developing this method. Cultural factors and food habits in Kendari City are varied so that most of the waste generated is organic waste. According to research [14], the composition of waste in Kendari City, the majority of which is food waste, reaches 56.5%. However, in other countries it is lower and even reduced by half. According to research conducted by Kalantarifar et al. amount of food waste is 30% in Malaysia [15]. Table 1 shows the quantity of waste stockpiled at the Puuwatu landfill for 17 years.

Table 1. Input data sheet to the LandGEM software for Puuwatu Landfill

Year	Waste Accepted		Waste-In-Place		Total landfill gas		
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2011	149.878	164.866	0	0	0	0	0
2012	161.454	177.599	149.878	164.866	3,111E+03	2,491E+06	1,674E+02
2013	169.316	186.248	311.332	342.465	6,311E+03	5,054E+06	3,396E+02
2014	177.431	195.174	480.648	528.713	9,519E+03	7,622E+06	5,121E+02
2015	185.803	204.383	658.079	723.887	1,274E+04	1,020E+07	6,853E+02
2016	194.438	213.882	843.882	928.270	1,597E+04	1,279E+07	8,594E+02
2017	203.342	223.676	1.038.320	1.142.152	1,923E+04	1,540E+07	1,035E+03
2018	212.522	233.774	1.241.662	1.365.828	2,251E+04	1,803E+07	1,211E+03
2019	221.983	244.181	1.454.184	1.599.602	2,583E+04	2,068E+07	1,390E+03
2020	231.731	254.904	1.676.166	1.843.783	2,918E+04	2,336E+07	1,570E+03
2021	241.774	265.951	1.907.897	2.098.687	3,256E+04	2,608E+07	1,752E+03
2022	252.117	277.329	2.149.671	2.364.638	3,600E+04	2,882E+07	1,937E+03
2023	262.768	289.044	2.401.789	2.641.967	3,947E+04	3,161E+07	2,124E+03
2024	273.732	301.105	2.664.556	2.931.012	4,300E+04	3,444E+07	2,314E+03

Year	Waste Accepted		Waste-In-Place		Total landfill gas		
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2025	285.018	313.520	2.938.288	3.232.117	4,659E+04	3,731E+07	2,507E+03
2026	296.631	326.294	3.223.306	3.545.637	5,023E+04	4,023E+07	2,703E+03
2027	308.580	339.438	3.519.937	3.871.931	5,394E+04	4,319E+07	2,902E+03

Regarding the flow of municipal solid waste to final processing sites, the half-life of organic materials such as food waste is too short for methane to be produced in landfills. Research by Tsatsarelis et al [21] states that methane production for textile and wood half-lives between 15 to 30 years appears to be almost the same. This indicates that the change also has no significant effect. Therefore, it is expected that the values of wood and textiles are small compared to other materials disposed of in landfills, leading to a relatively small contribution to methane production [21]. Table 2 shows the annual methane production from waste disposed of at the Puuwatu landfill, and its increasing methane production over time. According to Table 2, total methane production in 2011 was 8.311 × 102 Mg, increasing to 1.44 × 104 in 2027. Figure 1 shows the trend of methane gas emissions from year to year at the Puuwatu landfill. The results showed that the amount of waste produced per year at the Puuwatu landfill varied from 149,878 tons to 308,580 tons from the time the landfill was opened until the landfill was closed. The study of Sadeghi et al. [22] in Sanandaj showed that the rate of methane production in the first year of TPA operation was 10 m3/hour and reached 671 m/hour within 20 years (2014-2033) [22]. Comparison of this study with the results of Sadeghi et al. shows that the amount of methane production in landfills is lower, because the population is small, the amount of waste produced is lower.

Table 2. Production gases based on the LandGEM software for Puwatu Landfill

Year	Methane			Carbon dioxide		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2011	8,311E+02	1,246E+06	8,370E+01	2,280E+03	1,246E+06	8,370E+01
2012	1,686E+03	2,527E+06	1,698E+02	4,626E+03	2,527E+06	1,698E+02
2013	2,543E+03	3,811E+06	2,561E+02	6,976E+03	3,811E+06	2,561E+02
2014	3,402E+03	5,100E+06	3,427E+02	9,335E+03	5,100E+06	3,427E+02
2015	4,267E+03	6,396E+06	4,297E+02	1,171E+04	6,396E+06	4,297E+02
2016	5,137E+03	7,700E+06	5,173E+02	1,409E+04	7,700E+06	5,173E+02
2017	6,014E+03	9,014E+06	6,057E+02	1,650E+04	9,014E+06	6,057E+02
2018	6,899E+03	1,034E+07	6,948E+02	1,893E+04	1,034E+07	6,948E+02
2019	7,794E+03	1,168E+07	7,849E+02	2,138E+04	1,168E+07	7,849E+02
2020	8,698E+03	1,304E+07	8,760E+02	2,387E+04	1,304E+07	8,760E+02
2021	9,615E+03	1,441E+07	9,683E+02	2,638E+04	1,441E+07	9,683E+02
2022	1,054E+04	1,580E+07	1,062E+03	2,893E+04	1,580E+07	1,062E+03
2023	1,149E+04	1,722E+07	1,157E+03	3,152E+04	1,722E+07	1,157E+03
2024	1,244E+04	1,865E+07	1,253E+03	3,414E+04	1,865E+07	1,253E+03
2025	1,342E+04	2,011E+07	1,351E+03	3,682E+04	2,011E+07	1,351E+03
2026	1,441E+04	2,160E+07	1,451E+03	3,953E+04	2,160E+07	1,451E+03

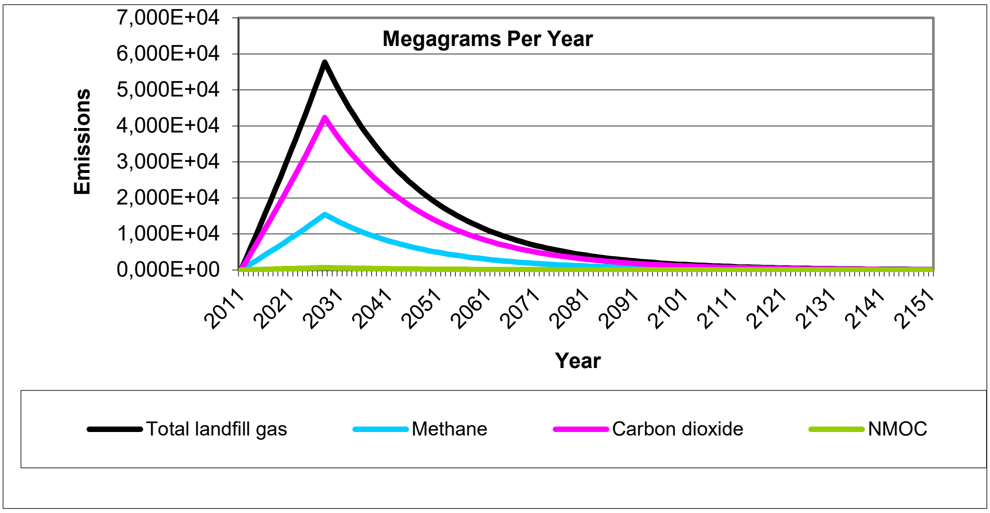

Fig.2. The amount of gas emission from Puwatu landfill from year 2011 to 2151

Conclusion

Methane gas emissions from landfill Puuwatu, Kota Kendari have been estimated using the LandGEM model. This landfill began operating in 2002 with an open dumping system, in 2008 the operation used a controlled landfield with the aim of receiving waste generated in the area until 2027. The amount of methane production from waste in 2011 reached 8.3 × 102 (Mg/year) , the first year after receipt of waste by landfill while the maximum methane production rate occurs during 2027 which is indicated as a production peak of 1.44 × 104 (Mg/year). The results of this study can be used to calculate in planning energy production and other uses of landfill gas and also determine Indonesia's contribution to global greenhouse gas emissions. In addition, because the quantity of methane gas is calculated, it is possible to design and implement a methane collection system for each storage site.

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