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Study of Estimation Methane Emissions from Municipal Solid Waste Landfill Based on IPCC Model (Case Study: Klotok Landfill, Kediri)

by Restu Hikmah Ayu Murti

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Research Study

Study of Estimation Methane Emissions from Municipal Solid Waste Landfill Based on IPCC Model (Case Study: Klotok Landfill, Kediri)

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Abstract

Sanitary landfill is the most common type of waste processing in Indonesia because it can minimize the negative impacts caused by waste and can utilize methane gas produced from the waste decomposition process. An analysis of the population projections of Kediri and waste generation was carried out to determine the waste generation at the Klotok Landfill. This study predicts methane gas emissions produced at the Klotok Landfill based on the IPCC method. This study uses two types of data: secondary and primary data. Secondary data includes the number of residents and waste entering the landfill, while the primary data used is waste composition. A sanitary landfill is needed in order to minimize the negative impact of solid waste, one of the negative impacts caused by solid waste is the formation of methane gas. This study uses the IPCC (Intergovernmental Panel Climate Change) model to calculate methane generation in the next ten years. The results show that population significantly impacts CH4 emissions from solid waste disposal facilities. Due to the city's growing urbanization and population increase, the production of waste in Kediri is increasing. Total waste production in 2032 is 723.98 m^3/day or 217,195.44 Kg/day. In contrast, the total percentage of waste that goes to the Landfill is around 55%, so the waste that goes to the landfill is around 398.19 m^3/day or 119.457.49 kg/day. In addition, the increase in the amount of solid waste at the Klotok landfill also produces methane gas. Based on the amount of waste that goes to the landfill, the projected methane gas formation from the IPCC model in 2032 can reach 6.148 Mg in a day.

Keywords: Klotok landfill; populations; waste generations; IPCC model; methane emission

1. Introduction

Over the final decades, fast urbanization in Indonesia has activated different natural issues. One of the foremost prominent issues is solid waste. One of environmental problem caused by solid waste is environmental air pollution caused by its gases, which 60% of the composition is methane. Methane generation in landfill poses significant problems, both locally and globally. At the local level it may cause health risks to nearby residents and the gas is prone to explosion (Rashkevich, et al, 2021).

The most common final treatment for waste in Indonesia is Sanitary landfills. The sanitary landfill system is a waste management system by piling and piling garbage in a sunken location, compacting it, and then backfilling it with soil (Murti, et al, 2022). The advantage of this sanitary landfill is that it can minimize the negative impacts caused by waste and can utilize methane gas produced from the waste decomposition process (Osama Ragab, 2019). In the city of Kediri, a Klotok Landfill is used to accommodate the waste produced by residents. Garbage that enters the Klotok landfill continues to increase along with population growth. Klotok landfill implements an open dumping system, where this system does not have any processing for the release of gas emissions so it becomes a potent greenhouse gas. The waste sector is the fourth most significant contributor to greenhouse gases after the forestry, agriculture, and industrial sectors (Andriani and Atmaja, 2019).

Klotok landfill has a relatively large amount of inorganic waste. The garbage continues to grow and forms a pile of garbage that gets taller over time. The pile of garbage at the bottom will experience anaerobic conditions (without oxygen), resulting in a decomposition process that produces methane gas. By 2020 methane from landfills contributed at least 14.5% of total methane emissions in the United States (US EPA, 2022)

The potential emission of methane gas is equivalent to 25 carbon dioxides (CO_2) (Börjesson et al., 2009). Methane gas has a Global Warming Potential (GWP) of 21. This value means that the weight of methane gas has the potential to heat the earth 21 times higher than the unit weight of carbon dioxide gas (CO_2) in 100 years. Methane gas is also more stable in the atmosphere than CO_2 because it cannot be absorbed by plant chlorophyll for photosynthesis (Nisa, Sitogasa and Mirwan, 2021).

Based on the IPCC Fourth Assessment Report, methane gas emissions from waste management accounted for 14.3% of global greenhouse gas emissions (Lando et al., 2021). Landfill gas emission estimates are required for greenhouse gas inventories. One of the methods for predicting methane emissions from waste in landfills is the 2006 IPCC (Intergovernmental Panel on Climate Change) method. This method uses data on population projections, waste generation, and the percentage of waste management. The model must be applied to all yearly volumes disposed of during the landfill disposal time since the wastes are not landfilled in a single year. As a result, the global biogas production is determined by adding the biogas produced by wastes that were landfilled in various years (Penteado et al., 2012).

In this study, the IPCC model was employed as a model that is considered capable of representing the amount of methane in a certain period because the IPCC scientifically uses mathematical models with various elements such as the humidity of a country, oxidation factor, methane correction factor, and degradable organic factor. The essential thing in the IPCC model is that it can predict the amount of methane produced based on the composition of the waste that goes into the landfill. Predictions based on the composition of this waste that other models do not have (IPCC, 2021).

Based on the description above, an analysis of the population projections of the city of Kediri and the generation of waste is carried out on waste at the Klotok Landfill. This study can be used to predict methane gas emissions produced at the Klotok landfill based on the IPCC method. In a previous study conducted by Harianto et al (Hariyanto et al., 2019), the potential for methane gas was measured by direct sampling using a gas sensor type MQ-04. However, the research does not consider the methane generation from each composition of the waste in the landfill. This study is conducted to fulfill the gap from previous research by calculating the potential of the methane gas in the landfill based on the waste generated by the people of Kediri and adjusted based on the real data of the waste entering the landfill. This study also considers the potential aspect of methane based on the composition of the waste, whose measurements are carried out directly by referring to SNI 19-3964-1994 with the consideration that each waste composition produces a different amount of methane.

The study of the amount of waste generated and its composition helps know the amount of methane produced and the type of waste that produces the most methane. Knowing the prediction of waste generation and the type of waste that produces the most methane can make it simpler when determining the management and processing of waste to minimize the methane gas produced.

2. Method

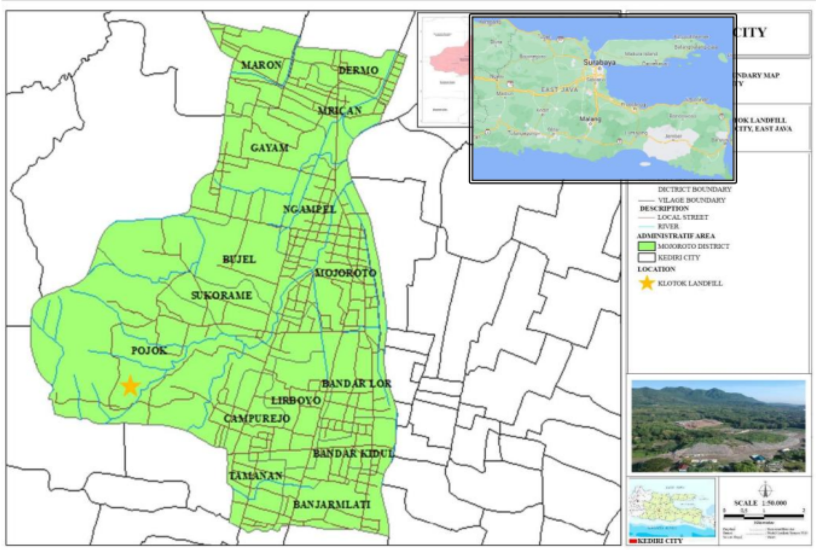
This study uses two types of data: secondary and primary data. Secondary data include the number of people, Total Area, Loading, and Unloading of solid waste in landfills, while the primary data used is the composition of solid waste. Secondary data was obtained from the official website provided by the government and data recorded from landfill management, while primary data was obtained from laboratory analysis results.

2.1. Site Descriptions

Klotok landfill is located in Kediri City, East Java Province. The Klotok Landfill accommodates the waste produced by the people in the city of Kediri. The city of Kediri is between 111°05′ – 112°03′ East Longitude and 7°45′ – 7°55′ South Latitude. As for the topographical aspect, the city of Kediri is at an average altitude of 67 meters above sea level. The slope is 0 – 40 percent.

According to the Central Statistics Agency (BPS) of East Java, until 2020 the population of Kediri City was 289.109 people/person (BPS, 2022). Kediri Regency borders Kediri City Both the north, west, south, and east. The Kediri City is also divided by an old river with the great history and heroism of the Brantas River. The area of Kediri City is 67.2 km², administratively divided into three sub-districts: Mojoroto District, City District, and Pondok Pesantren District(BPS, 2022).

Figure 1. Site location of Klotok Landfill Kediri



2.2. Solid Waste Compositions

Sampling regarding the composition of waste is carried out by referring to SNI 19-3964-1994(Badan Standarisasi Nasional, 1994) regarding the method of taking and measuring samples of the generation and composition of urban waste. According to the MSW's confinement duration, the study region was separated into three quadrants, quadrant I being the oldest and quadrant III being the most recent. To ensure less effect from outside factors like variations in humidity and temperature, measurements were done in the morning (between 9:00 AM and 13:00 PM). Green waste, paper, and cardboard, plastics, sanitary (diapers and sanitary towels), and textile categories were recognized manually. Composition is commonly used to express each component in the generated waste (Tchobanoglous, G., & Kreith, 1993). The waste classification is based on the composition expressed as % by weight (usually wet weight) or % by volume (wet) of waste. Paper, wood, leather, rubber, plastic, metal, glass, cloth, food, and others (Damanhuri, E., & Padmi, 2010).

2.3. Population Growth Rate

An important factor in calculating the rate of waste generation is the population. Therefore, before the amount of waste generation can be calculated, the population projection is calculated first. In this study, the researchers used the arithmetic method because population growth tends to be linear (Bartlett, 1993).

$$P_n = P_o + r(t) \quad (1)$$

$$r = \frac{1}{t}\left(\frac{Pt}{Po} - 1\right) \quad (2)$$

where,

Pn : Total population at the end of the year period
Po :Total population at the beginning of the projection
r : Average population growth per year
t : Projection period.

2.4. Solid Waste Generation (SWG) Calculation

The calculation of waste generation in the City of Kediri needs to be done to find out the total amount of waste that exists. In this study, the data on the amount of waste generated was not obtained from sampling but from secondary data obtained from the waste management agency in the City of Kediri. Currently, the available data are in units of kg/person/day or l/person/day, so to find out the average of all urban waste produced, it is necessary to calculate. the following formula to calculate:

SWG = Generation Rate × Total Population
= ……… kg/day or l/day………… (3)

Several studies provide urban waste generation rates in Indonesia it ranges from 2,3 liters/person/day with a density of 200-300 kg/m^3 (Damanhuri, E., & Padmi, 2010).

2.5. IPCC Model

This study using IPCC model tier one as a method to calculate methane generation in next ten year. The IPCC Waste Model is a Microsoft Excel application created to make it simple to follow the IPCC protocol when estimating national landfill methane emissions using the first-order decay model (Krause, 2018). Depending on the quantity and quality of the data, it can be run as a single-phase or multiphase model (i.e., food, yard, paper, etc.). Each year, the calculation is about the amount of carbon stored and methane produced. To compute landfill methane emissions in 2006, methane that has been collected in a gas collection and control system and an oxidation factor can be given. The model contains all of the parameters and default values examined in this examination (Penman et al., 2006). It covers 17 geographical regions, and for single-phase computations, this determines the default MSW Degradable Organic Carbon (DOC) concentration. Each waste component in the multiphase model has distinct DOC content ranges and default values (e.g., paper and food). The DOC content is unaffected by the location, though.

2.6. Methane Generation Calculations

The equation below can be used to estimate methane (CH_4) generation. Based on the volume and make-up of the garbage dumped at Klotok Landfill and the procedure used for waste management there, the potential for methane generation over time will be calculated. The amount of Decomposable Degradable Organic Carbon ($DDOC_m$), the portion of organic carbon that will decompose under anaerobic circumstances in a landfill, is the basis for the computation. The calculation of $DOOC_m$ expressed as:

$$DDOC_m = DOC \times DOC_f \times W \quad (4)$$

Where DOC_f is the fraction of DOC that can be composed, and W is the mass of solid waste. The potential methane on solid waste (Lo) mathematicaly expressed:

$$L_o = DDOC_m \times F \times \frac{16}{12} \quad (5)$$

Where F is the fraction of methane and 16/12 is the molecular weight of ratio CH_4

Following are the amounts of DDOCm that had accumulated and decomposed at the conclusion of the year (T).

$$DDOC_{maT} = DDOC_{mdT} + \left(DDOC_{maT_{-1}e}{}^{-k}\right) \qquad (6)$$

Where:

$DDOC_{mdT}$= $DDOC_m$ disposed into landfill in T(year)

$DDOC_{maT}$= Accumulation of DDOC on landfill in the end of T,

k= reaction constan,t and

$DDOC_{m\ decompT}$ =$DOOC_m$ into landfill in T (year)

The equation below illustrates how methane is produced when decomposable material breaks down.

$$\text{Methane generatedT} = DDOC_{m\ decompT} \times F \times \frac{16}{12} \qquad (7)$$

3. Result and Discussion

3.1. Solid Waste Composition

The results of data analysis show that plastic waste is still dominant among other components in quadrants I and II, it is caused by quadrant I is the oldest and quadrant III is the most recent. The organic matter in quadrant I demonstrate the impact of the site's time of solid waste disposal on the organic fraction concentration. As observed in quadrant I to the more recent quadrants, the oldest quadrants contain a lower content of organic waste.

Table 1. Percent solid waste composition Klotok Landfill

Category	Quadrant (%)			Average (%)
	I	II	III	
Food waste	0	0	2.2	0.73
Garden	1.2	2.4	30.1	11.23
Paper	30.5	20.5	17.97	22.99
Wood and straw	10.4	15.6	18.3	14.76
Textiles	5.3	7.4	1.15	4.61
Disposable nappies	2.1	1.1	3.1	2.1
Plastic	50.5	53	27.18	43.56

Source: Reseacher analysis, 2022

The landfill gas produced chiefly relies on the local environment, including the climate, geography, waste types, and other elements. Numerous experts have determined the elements that affect how MSW degrades and have evaluated each element's impact on methane production (CHIEMCHAISRI *et al.*, 2012)(González *et al.*, 2011). Currently, applications to reduce waste from garden are carried out by composting, which can minimize garden waste that goes to the landfill.

3.2. Population Growth Rate

The population is the main factor in determining how much solid waste is produced in Kediri. Using public data for nations with comparable socioeconomic factors to calculate the amount of waste produced per capita daily is one way of calculating the overall quantity of solid waste produced. The total amount of waste generated can be calculated by multiplying this number by the population under investigation.

Table 2 shows the population data in Kediri City during 2010-2020. Using aritmatic method from that data it can be projected in the next ten years, with average population growth per year is 74%. Standard deviation and coeffisien correlation were employed to know suitability of the model with the data. The value of standard deviation is 6605.38 with strong coeffisien correlation is 0.9973 it can conclude that the model is perfectly fit with the data. The prediction of aritmatic model in 2032, the total population in Kediri City can reach 314.776 person.

Table 2. Total population Kediri City in ten years

Year	Total Population (inhabitants)
2010	269193
2011	271 511
2012	273695
2013	276619
2014	278072
2015	280004
2016	281 978
2017	284003
2018	285 582
2019	287409
2020	289109

Source: Central Bureau of Statistics, 2022 (BPS, 2022)

3.3. Solid Waste Generation

According to a world assessment, the population is one of the factors causing an increase in trash generation from 1.3 million tons year to 2.2 million tons annually by 2025 (Ayob and Sheau-Ting, 2016). In line with Hadi's finding the population's wealth directly influences the rates and varieties of solid waste. Waste production often rises along with the population's consumer spending (Hadi, 2014). Based on equation 3, amount of solid waste production in Kediri City can be calculated.

According to waste data collection report from Department of the Environment of the city of Kediri (DLHKP, 2022) in latest three years the average solid waste that dump to Klotok landfill is around 55% from total solid waste production in a day. The total number of solid wastes which enter the landfill is relatively high, this is inseparable from the dominant view of the community, which still relies on the end-of-pipe approach. However, the Government of Kediri City has tried to socialize waste management from the source to help reduce the volume of waste that goes to the landfill.

Table 3. Total solid waste generation Kediri City

Year	Total Population (inhabitants)	Total Solid Waste Generation (m^3/day)	Total Solid Waste (Kg/day)
2010	269.193	619.143	123,828.78
2011	271.511	624.475	124,895.06
2012	273.695	629.498	125,899.7
2013	276.619	636.223	127,244.74
2014	278.072	639.565	127,913.12
2015	280.004	644.009	128,801.84
2016	281.978	648.549	129,709.88
2017	284.003	653.206	130,641.38
2018	285.582	656.838	131,367.72
2019	287.409	661.040	132,208.14
2020	289.109	664.950	132,990.14

Source: Reseacher analysis results, 2022

Figure 2 shows the material balance of solid waste in Kediri City. Around 35% of Solid waste production in Kediri City are handled on solid waste management, the District Government of Kediri trying to maximize the (Reduce, Reuse and Recycle) 3R concept by establish the waste bank and composting area (DLHKP, 2022). The number of unhandled solid waste in Kediri City is around 10%, which may associate with the habit of people in developing to burn the garbage (Ferronato and Torretta, 2019).

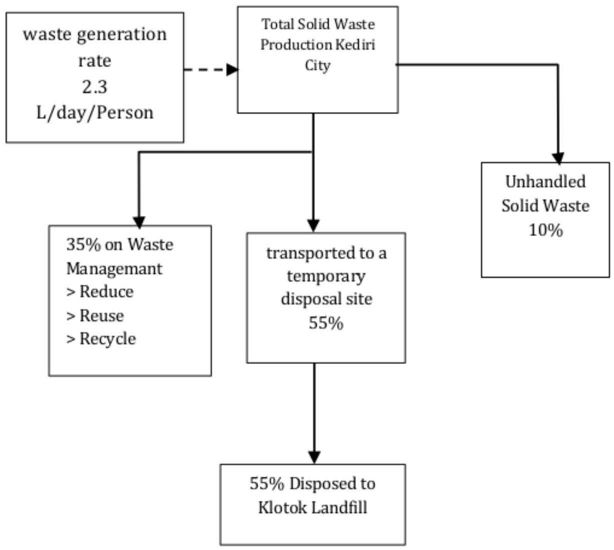


Figure 2. Material balance solid waste Kediri in 2020
Source: (DLHKP, 2022)

Based on the projection calculation of the total population of Kediri in the next ten years, the total population can reach 314,776 people. Using equation 3 the total number of waste production in 2032 cancalculated assuming that the percentage of waste that goes to landfill is still the same. The total number of waste production in 2032 is 723.98 m3/day or 217,195.44 kg/day. The total percentage of solid waste that enter to landfill is around 55%, it can conclude that the solid waste enter to landfill is around 398.19 m^3/day or 119,457.49kg/day.

3.4. IPCC Model in Predicting of Methane Gas Production

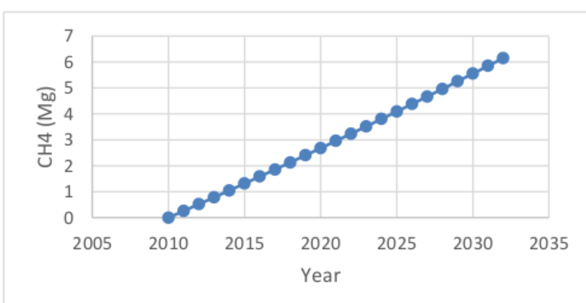
The IPCC Guideline 2006 method, which contained an equation integrating information on waste generation, degraded organic matter content, landfill conditions, and methane production, was the default approach model employed. The population of the city of Kediri served as the model's input data. Additionally, the IPCC Guideline 2006 approach was used to process the population data to determine waste generation values. Waste generation on model was solid waste that enter to landfill, which 55% from total solid waste generation from Kediri City. Table 4 shows, the IPCC model result using IPCC 2006 guideline. Table 4 simulate the total methane generation in a day from 2010 until 2032. Figure 2 below presents the predictions of methane emissions (CH_4) based on solid waste that enter Klotok landfill. The amount of methane rapidly increases in line with the amount of waste generated per day in the Klotok landfill, it can reach 6,148 Mg/ day methane in 2032. This number is relatively smaller if compared to methane production landfill in West Java (Wijaya, Ainun and Permadi, 2021). The investigation of total methane prediction based on solid waste composition in Klotok Landfill run with the same method. The result of methane based on the solid waste composition beneficially to know type of solid waste that produce greater methane in a day. Food waste is an organic material with a high calorific content and nutritional value for bacteria, which can greatly boost the efficiency of methane production (Al Saadi and Rao, 2016). The amount of food waste is 0.73% from total solid waste that enter Klotiok landfill. However, food waste is the most active fraction in Landfill, due to food waste is biodegradable material (Adhikari, Barrington and Martinez, 2006). Based on IPCC model DOC of food waste is 0.15 with fraction of DOC dissimilated 0.5.

Table 4. Methane generation Klotok landfill in 2010-2032

Year	Waste Generation Klotok Landfill (Mg)	DDOCm (Mg)	Lo	DDOC mat (Mg)	DDOCm decompT (Mg)	CH_4 (Mg)
2010	102.158	6.165	4.110	6.16	0	0
2011	103.038	6.218	4.145	12.38	0.387	0.258
2012	103.867	6.268	4.178	18.652	0.779	0.519
2013	104.976	6.335	4.723	24.987	1.173	0.782
2014	105.528	6.368	4.245	31.356	1.572	1.048
2015	106.261	6.412	4.275	37.768	1.973	1.315
2016	107.010	6.458	4.305	44.227	2.376	1.584
2017	107.779	6.504	4.336	50.731	2.783	1.855
2018	108.378	6.540	4.360	57.272	3.192	2.12
2019	109.071	6.582	4.388	63.854	3.604	2.402
2020	109.716	6.621	4.414	70.476	4.018	2.679
2021	110.528	6.670	4.446	77.146	4.435	2.956
2022	111.340	6.719	4.479	83.865	4.855	3.236
2023	112.152	6.768	4.512	90.634	5.27	3.518
2024	112.963	6.817	4.544	97.451	5.703	3.802
2025	113.775	6.866	4.577	104.317	6.132	4.08
2026	114.587	6.915	4.610	111.233	6.564	4.376
2027	115.398	6.964	4.642	118.197	7.00	4.666
2028	116.210	7.0133	4.675	125.210	7.438	4.958
2029	117.022	7.062	4.708	132.273	7.878	5.253
2030	117.834	7.111	4.740	139.384	8.324	5.549
2031	118.645	7.160	4.773	146.544	8.771	5.847
2032	119.457	7.209	4.806	153.754	9.22	6.148

Source: Research Analysis. 2022

Figure 2. Total methane production in Klotok Landfill in 2010-2032



Source: Researcher's Analysis

Figure 2 depict the methane generation prediction in ten years. This figure predict the methane generation from total inhabitant in Kediri City. with assumption 100% of total solid waste entering the Klotok Landfill. Along with the increase in population in Kediri. the amount of methane gas produced also increases. It is predicted that in 2032 the amount of methane gas in Kediri could reach around 6.148 megatons (Mg).

Table 5. IPCC Model result for methane gas emission

Year	Amount deposited (Mg)	MCF fraction	CH_4 generated (Mg)				
			(Food waste)	Paper	Wood and Straw	Textiles	Nappies
2010	0.745	0.71	0.000	0.000	0.000	0.000	0.000
2011	0.752	0.71	0.008	0.150	0.053	0.018	0.019
2012	0.758	0.71	0.014	0.292	0.104	0.035	0.035
2013	0.766	0.71	0.018	0.425	0.154	0.051	0.049
2014	0.770	0.71	0.021	0.551	0.203	0.066	0.061
2015	0.775	0.71	0.023	0.669	0.251	0.080	0.071
2016	0.781	0.71	0.024	0.780	0.297	0.094	0.080
2017	0.786	0.71	0.025	0.885	0.342	0.106	0.087
2018	0.791	0.71	0.026	0.983	0.386	0.118	0.094
2019	0.796	0.71	0.027	1.076	0.429	0.129	0.099
2020	0.800	0.71	0.02	1.164	0.470	0.140	0.104
2021	0.806	0.71	0.027	1.247	0.511	0.150	0.108
2022	0.812	0.71	0.028	1.325	0.550	0.159	0.112
2023	0.816	0.71	0.028	1.399	0.589	0.168	0.115
2024	0.824	0.71	0.028	1.470	0.627	0.177	0.118
2025	0.830	0.71	0.028	1.537	0.663	0.185	0.121
2026	0.836	0.71	0.029	1.600	0.699	0.193	0.123
2027	0.842	0.71	0.029	1.661	0.735	0.200	0.125
2028	0.848	0.71	0.029	1.718	0.769	0.207	0.127
2029	0.854	0.71	0.029	1.773	0.802	0.213	0.129
2030	0.860	0.71	0.029	1.825	0.835	0.220	0.131
2031	0.86	0.71	0.030	1.875	0.867	0.226	0.132
2032	0.87	0.71	0.030	1.923	0.899	0.231	0.134

Figure 3 depict the methane generation based on solid waste composition in Klotok Landfill. Due to the high accumulation of paper disposed into Klotok landfill paper becomes material that produces the most methane. it can reach 1.923 Mg/ day in 2032. Textile becomes the material with lowest methane production. since textile waste mostly shorted out by scavengers. Based on tke solid waste composition in Klotok landfill. amount of plastic waste is the greatest. Plastic in Klotok landfill assumed as non-biodegradable material.

One of the main sources of anthropogenic emissions is methane from landfills (Chiemchaisri *et al.*. 2012). Methane content in the atmosphere has increased by more than a factor of two in the past 150 years. Methane is the third most significant GHG after carbon dioxide and water vapor. The global warming potential of CH4 over a century is 25 times greater than that of an equivalent quantity of CO2(Penman *et al.*. 2006).

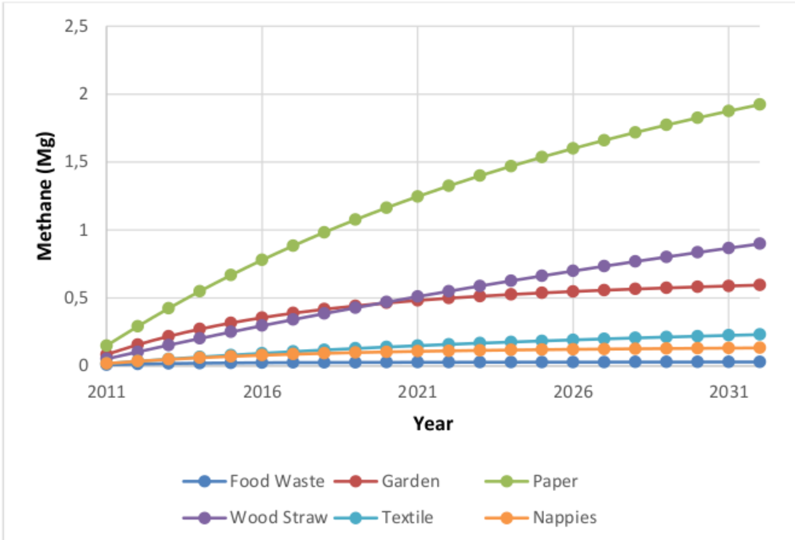


Figure 3. IPCC model on methane generation by solid waste composition in Klotok Landfill
Source: Researcher's Analysis. 2022

Methane emissions from landfills in Klotok landfill will keep rising since the population number in Kediri city increasing. Integrated Solid Waste Management (ISWM) is one of the most successful strategies for combating environmental deterioration and cities sustainably (Sitogasa. 2022). In addition. reducing waste that goes to a landfill can also have a significant impact on the amount of methane produced. One of the ways to reduce waste that goes to landfill is by optimizing the 3R (Reduce. Reuse and Recycle) strategy. Methane emissions can be significantly reduced with modern extraction methods from landfills. Producing electricity and promoting smart compost are other ways to make the most of this underutilized resource.

4. Conclusions

The population has quite a significant impact on CH_4 emissions from solid waste disposal facilities in the nation (Gollapalli and Kota. 2018). due to the city's growing urbanization and population increase. Kediri's trash production has been rising. Municipalities must cope with this by using a significant amount of their financial and human resources to provide and manage solid waste services. In addition. increasing the amount of solid waste in an open landfill. as shown in Figure 2. has resulted in methane generation. The projection methane generation from IPCC model in 2032 can reach 6.148 Mg in a day.

Waste processing at Klotok Landfill currently uses a sanitary landfill system to avoid the negative impacts caused by the open dumping system. However. a sanitary landfill without proper treatment still has some negative effects. one of them is the negative impact of air pollution caused by CH_4. Every landfill site is preferable for having CH_4 collection systems designed and put into place based on the amount of methane gas determined by the IPCC model. The usage of CH_4 gas collection system is to decreased gas buildup in landfills. avoided landfill explosions. and avoided gas leakage into the aquifer.

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