Estimation of methane emissions from municipal solid waste landfill in Makassar city based on IPCC waste model

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Abstract. One of the greenhouse gases, which is the cause of climate change and global warming is methane gas (CH₄). One of the most significant sources of methane that contributes to emissions globally is landfills (anthropogenic sources). Methane emissions from waste are the result of the anaerobic decomposition of organic matter in waste. The more garbage in the landfill without further treatment can lead to greater methane emissions. The site of this study was a municipal solid waste in Makassar city, named Tamangapa landfill, ± 15 km from downtown Makassar city. The objectives of this study are to estimate methane emissions in the Tamangapa landfill and estimate methane emissions from the Tamangapa landfill over the next ten years using the 2006 IPCC Waste Model. The results showed that the waste generation in Makassar City, in 2016, was 0.449 kg/person/day with the composition of waste dominated by organic waste. The value of potential methane emissions at TPA Tamangapa Makassar in 2016 is 2.24 Gg/year and the projection in 2026 is 4.968 Gg/year. The mitigation and adaptation efforts that can be recommended are the socialization of 3R techniques (Reduce, Reuse, and Recycle) and construct a sanitary landfill in Makassar city following the mandate of Law No. 18 of 2008.

1. Introduction
Waste is a significant problem experienced by urban areas, including in Makassar City. In big cities, municipal solid waste (MSW) is a big problem both in terms of number and type of waste, where it grows along with the population growth in the city. Related to global warming, the potential for greenhouse gases (GHG) production is related to the generation and the composition of waste, especially organic waste. Global warming in the climate system is tangible. Since 1950, many researchers have observed extraordinary changes for decades to centuries. The atmosphere and oceans are heating up, the amount of snow and ice is decreasing, sea levels are increasing, and the concentration of GHG has become higher. Sustainable GHG emissions will lead to more significant warming and change in all segments of the climate system [1].

The Fifth Assessment Report of the Working Group III as the latest Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) states that GHG emissions continue to increase from 1970 to 2010. GHG emissions from the human activity sector are proliferating in recent years (2000 to 2010). In 2010, GHG emissions reached 49.5 billion tons (gigaton or Gt) of carbon dioxide (CO₂) equivalent. This number is the largest in human history [2]. GHG are gases in the atmosphere that cause climate change and global warming. These GHG include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and chlorofluorocarbon (CFC). Climate change can occur directly or...
indirectly due to human activities (anthropogenic), which change the composition of the global atmosphere, and also natural climate variability [3]. Based on the IPCC, CH₄ has an effect of 20-30 times greater than CO₂. CH₄ is one of the second largest GHG (Kyoto Protocol) after CO₂, whose global warming potential is 28 times greater than CO₂. Based on the IPCC Fourth Assessment Report, total CH₄ emissions from global GHG emissions are 14.3%, and 2.8% come from waste management [4]. The CH₄ emissions from waste management shared 4% of the global total GHG emissions in 2010 [5], with about half both from municipal solid waste (MSW) landfill and wastewater treatment. The waste generation and landfill are substantially increasing along with economic development, the advance of urbanization, and the improvement of people’s living standards. Comprehensive and accurate estimation of the CH₄ emissions from landfills is increasingly essential in waste management and the improvement of people’s living standards. Comprehensive and accurate estimation of the CH₄ emissions from landfills is increasingly essential in waste management and the improvement of people’s living standards.

Makassar City is the tenth-largest city in Indonesia according to its population, which is 1,449,401 people [8]. In 2016 the number of waste generation in the city of Makassar reached 4183.41 m³/day, while the one handled was 3,962.63 m³/day, which was 95.37% of the generation [9]. Previous studies from Lando et al., 2015, 2016, 2017, have reported that the concentration and emissions of methane from MSW landfill in Makassar City, named Tamangapa landfill, are in a very varied range, from 12 - 425 ppm for methane concentrations and 2.44 - 18 Gg/year for methane emissions [10,11,12].

Based on the description above, further study will conduct to analyze waste generation and population growth rates of Makassar City. This study will be a reference for estimating methane emissions that occur in the Tamangapa landfill in Makassar city. The objectives of this study are to estimate existing methane emissions in the Tamangapa landfill and to predict methane emissions in the Tamangapa landfill for the next ten years.

2. Methods
The theoretical framework of this study is prepared based on references from the previous study, journals, and research articles. Furthermore, this study collects two kinds of secondary data, namely population and municipal solid waste generation data of Makassar city in the last ten years. Data processing, analysis, and discussion of methane emission estimation based on (1) waste generation and waste characteristics in the municipal solid waste landfill (Tamangapa landfill) and (2) population in Makassar city using the IPCC Waste Model 2006.

2.1. Study site
This study takes solid waste generation (composition and characteristics) data from the Tamangapa landfill. Tamangapa landfill (Figure 1), is the only municipal solid waste landfill in the city of Makassar, owned by the Municipal Government of Makassar City. This landfill is at coordinates S 5.17520; E 119.49350, and ± 15 km from downtown Makassar. The Tamangapa landfill began operations in 1993 until now with a designed capacity is 2,15 million tons of waste. Since it was operated from 1993 until 2014, the landfill area is 14.3 Ha. However, due to the increasing volume of waste in the city of Makassar, there is an expansion of land for several zones. Therefore, in 2015, the Tamangapa landfill area has increased to ± 16.8 Ha. This landfill is an open dump disposal site, no daily cover soil, bumpy surface, no vegetation on the top surface, and nowadays, the waste heap in Tamangapa landfill has reached 20 meters. This height makes a steep slope in each zone of the landfill. However, there is no certainty from the government when this landfill will be closed. As a comparison, according to the World Bank Data in 2007, since this landfill opening, an estimated 1.4 million tons of MSW has been disposed of to this landfill with a current waste volume of approximately 1.800.000 m³.
2.2. Study methods

The method used in calculating CH$_4$ emissions produced from a waste generation at the Tamangapa landfill using the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines approach (IPCC Waste Model 2006). The 2006 IPCC Guidelines are methods that can be applied to all countries or regions because the guidelines provide default values, estimates, and calculation methods to overcome the lack of data using the emission factor determined by the IPCC. The default data used from IPCC 2006 in the calculation of waste generation is as follows.

![Figure 2. The default value of waste generation is based on region.](image-url)
Figure 3. The default value of waste generation for each characteristic is based on region.

![Image](image-url)

Figure 4. The default value of the weighted average of the methane correction factor (mcf) for msw and industrial waste.
2.3. Methane generation
Methane (CH$_4$) generation can be estimated by the given equation below. The potential of methane generation throughout the years will be estimated based on the amounts and composition of the waste disposed into Tamangapa Landfill and practices of waste management at the landfill. The calculation basis is the amount of Decomposable Degradable Organic Carbon (DDOCm), the part of the organic carbon that will degrade under anaerobic conditions in a landfill (Eq.1).

$$DDOC_m = W \cdot DOC \cdot DOC_f \cdot MCF$$

where:
- $DDOC_m$ = mass of decomposable DOC deposited, Gg
- $W$ = mass of waste deposited, Gg
- $DOC$ = degradable organic carbon in the year of deposition, fraction, Gg C/Gg
- $DOC_f$ = fraction of DOC that can decompose (fraction)
- $MCF$ = CH4 correction factor for aerobic decomposition in the year of deposition (fraction)

The equation of transformation mass of decomposable DOC deposited to methane generation potential is given below.

$$L_0 = DDOC_m \cdot F \cdot 16/12$$

where:
- $L_0$ = CH4 generation potential, Gg CH4
- $F$ = fraction of CH4 in generated landfill gas (volume fraction)
- $16/12$ = molecular weight ratio CH4/C (ratio)

Accumulated and decomposed of $DDOC_m$ in the landfill at the end of the year (T) are given below.

$$DDOC_{maT} = DDOC_{mdT} + (DDOC_{maT-1} \cdot e^{-k})$$

$$DDOC_{m, decompT} = DDOC_{maT-1} \cdot (1 - e^{-k})$$

where:
\( T \) = inventory year  
\( DDOC_{maT} \) = \( DDOCm \) accumulated in the SWDS at the end of year \( T \), Gg  
\( DDOC_{maT-1} \) = \( DDOCm \) accumulated in the SWDS at the end of year \( (T-1) \), Gg  
\( DDOC_{mdT} \) = \( DDOCm \) deposited into the SWDS in year \( T \), Gg  
\( DDOC_{decompT} \) = \( DDOCm \) decomposed in the SWDS in year \( T \), Gg  
\( k \) = reaction constant, \( k = \ln(2)/t_{1/2} (y^{-1}) \)  
\( t_{1/2} \) = half-life time (y)

Methane generation from decomposable material can be seen in the equation below.

\[
\text{Methane generated}_T = DDOC_{m\text{decomp}T} \cdot F \cdot \frac{16}{12} \tag{5}
\]

2.4. Methane emissions

The emissions of methane from the Tamangapa landfill could be estimated using IPCC Waste Model (Eq.6). Methane generation is a result of organic material degradation under anaerobic conditions. Part of the methane generation is oxidized in the cover of the landfill or can be recovered for energy or flaring. Methane emissions from a landfill will hence be smaller than the amount generated.

\[
\text{Methane Emissions} = \left[ \sum_x \text{Methane generated}_{x,T} - R_T \right] \cdot (1 - OX_T) \tag{6}
\]

where:

- \( \text{Methane Emission} \) = Methane emitted in year \( T \), Gg  
- \( T \) = inventory year  
- \( x \) = waste category or type/material  
- \( R_T \) = recovered CH4 in year \( T \), Gg  
- \( OX_T \) = oxidation factor in year \( T \), (fraction)

3. Result and discussions

Waste generation in Tamangapa Landfill uses waste data that has entered the landfill over the past five years, and its prediction uses the geometry method. The amount of waste generated in the Tamangapa Landfill from the 2010-2016 data has increased. Methane (CH\(_4\)) emissions were calculated using the 2006 IPCC Waste Model formula based on 2010 and 2011 data for subsequent years (Table 1). The results of the calculation of methane emissions (CH\(_4\)) can be seen in Figure 4. That figure shows that each year, methane emissions (CH\(_4\)) have increased from 2011-2016, where the highest increase occurred in 2013-2014, which is around 0.51 Gg compared to other years. The prediction results of methane emissions (CH\(_4\)) based on population and waste generation can be seen in Figure 5.

| Year | Population | Waste Generation (kg) | \( DDOC_m \) (Gg) | \( L_0 \) (Gg) | \( DDOC_{maT} \) (Gg) | \( DDOC_{mdT} \) (Gg) | \( DDOC_{decompT} \) (Gg) | CH\(_4\) (Gg) |
|------|------------|-----------------------|------------------|---------------|------------------|------------------|------------------|-------------|
| 2010 | 1,339,374  | 194,451.559           | 9,392            | 6,261         | 9,392            | 0                | 0                | 0           |
| 2011 | 1,352,136  | 193,405.111           | 9,322            | 6,215         | 18,151           | 0,563            | 0,375            |
| 2012 | 1,369,606  | 203,419.001           | 9,823            | 6,549         | 26,886           | 1,089            | 0,726            |
| 2013 | 1,408,072  | 246,970.841           | 11,940           | 7,960         | 37,213           | 1,613            | 1,075            |
| 2014 | 1,429,242  | 247,182.733           | 11,940           | 7,960         | 46,920           | 2,232            | 1,488            |
| 2015 | 1,449,401  | 246,271.225           | 11,894           | 7,929         | 56,000           | 2,815            | 1,876            |
| 2016 | 1,469,601  | 237,851.884           | 11,486           | 7,657         | 64,127           | 3,360            | 2,240            |
3.1. Methane emissions from organic waste
Calculation of methane emissions (CH4) in organic waste generation is carried out to determine the methane emissions from generation per waste characteristics in the Tamangapa Landfill. This calculation can be seen in Table 2. To obtain the value of methane emissions (CH4) in organic waste using data from 2010-2011 as a review, then for the following years can be done following that data. Moreover, the prediction of methane emissions from the organic waste sector can be seen in Table 3.
Table 2. Methane emissions from organic waste.

| Year | Waste Generation (kg) | DDOC_m (Gg) | Lo (Gg) | DDOC_maT (Gg) | DDOC_m_decompT (Gg) | CH_4 (Gg) |
|------|-----------------------|-------------|---------|----------------|---------------------|-----------|
| 2010 | 149.533.248.9         | 7.966       | 5.311   | 7.966          | 0.000               | 0.000     |
| 2011 | 144.686.363.5         | 7.692       | 5.128   | 15.295         | 0.637               | 0.425     |
| 2012 | 147.926.297.5         | 7.879       | 5.253   | 21.764         | 1.224               | 0.816     |
| 2013 | 187.006.320.8         | 9.972       | 6.648   | 27.902         | 1.741               | 1.161     |
| 2014 | 189.638.592.8         | 10.104      | 6.736   | 35.642         | 2.232               | 1.488     |
| 2015 | 186.476.571.6         | 9.934       | 6.623   | 42.894         | 2.851               | 1.901     |
| 2016 | 182.479.965.4         | 9.720       | 6.480   | 49.397         | 3.432               | 2.288     |

Table 3. Prediction of methane emissions from organic waste.

| Year | Waste Generation (kg) | DDOC_m (Gg) | Lo (Gg) | DDOC_maT (Gg) | DDOC_m_decompT (Gg) | CH_4 (Gg) |
|------|-----------------------|-------------|---------|----------------|---------------------|-----------|
| 2017 | 232.706.782.7         | 9.720       | 6.480   | 55.165         | 3.952               | 2.634     |
| 2018 | 238.754.495.7         | 9.852       | 6.568   | 60.471         | 4.413               | 2.942     |
| 2019 | 244.959.379.9         | 9.984       | 6.656   | 65.485         | 4.838               | 3.225     |
| 2020 | 251.325.520.2         | 10.249      | 6.832   | 70.231         | 5.239               | 3.493     |
| 2021 | 257.857.107.2         | 10.381      | 6.921   | 74.861         | 5.618               | 3.746     |
| 2022 | 264.558.440.7         | 10.513      | 7.009   | 79.253         | 5.989               | 3.993     |
| 2023 | 271.433.932.2         | 10.645      | 7.097   | 83.426         | 6.340               | 4.227     |
| 2024 | 278.488.107.8         | 10.778      | 7.185   | 87.397         | 6.674               | 4.449     |
| 2025 | 285.725.611.2         | 10.910      | 7.273   | 91.183         | 6.992               | 4.661     |
| 2026 | 293.151.206.9         | 11.042      | 7.361   | 94.798         | 7.295               | 4.863     |

3.2. Methane emissions from paper waste

Methane emissions from the paper waste sector for 2010-2016 and its prediction from 2017 to 2026 can be seen in Table 4 and Table 5, respectively.

Table 4. Methane emissions from paper waste.

| Year | Waste Generation (kg) | DDOC_m (Gg) | Lo (Gg) | DDOC_maT (Gg) | DDOC_m_decompT (Gg) | CH_4 (Gg) |
|------|-----------------------|-------------|---------|----------------|---------------------|-----------|
| 2010 | 16.567.273            | 2.354       | 1.569   | 2.354          | 0.000               | 0.000     |
| 2011 | 17.038.990            | 2.416       | 1.610   | 4.613          | 0.094               | 0.063     |
| 2012 | 19.467.198            | 2.765       | 1.843   | 6.844          | 0.185               | 0.123     |
| 2013 | 20.671.459            | 2.939       | 1.960   | 9.336          | 0.274               | 0.183     |
| 2014 | 21.232.997            | 3.017       | 2.011   | 11.902         | 0.373               | 0.249     |
| 2015 | 20.612.902            | 2.928       | 1.952   | 14.442         | 0.476               | 0.317     |
| 2016 | 20.431.477            | 2.902       | 1.935   | 16.793         | 0.578               | 0.385     |
Table 5. Prediction of methane emissions from paper waste.

| Year | Waste Generation (kg) | $\text{DDOC}_m$ (Gg) | $\text{Lo}$ (Gg) | $\text{DDOC}_{\text{maT}}$ (Gg) | $\text{DDOC}_{\text{m decompT}}$ (Gg) | $\text{CH}_4$ (Gg) |
|------|-----------------------|----------------------|------------------|-------------------------------|----------------------------------|------------------|
| 2017 | 20.142.565,83         | 2.902                | 1.935            | 19.023                        | 0.672                            | 0.448            |
| 2018 | 20.712.770,21         | 2.942                | 1.961            | 21.164                        | 0.761                            | 0.507            |
| 2019 | 21.299.116,18         | 2.981                | 1.987            | 23.259                        | 0.847                            | 0.564            |
| 2020 | 21.902.060,68         | 3.060                | 2.040            | 25.310                        | 0.930                            | 0.620            |
| 2021 | 22.522.073,59         | 3.099                | 2.066            | 27.358                        | 1.012                            | 0.675            |
| 2022 | 23.159.638,09         | 3.139                | 2.093            | 29.363                        | 1.094                            | 0.730            |
| 2023 | 23.815.251,04         | 3.178                | 2.119            | 31.327                        | 1.175                            | 0.783            |
| 2024 | 24.489.423,37         | 3.218                | 2.145            | 33.252                        | 1.253                            | 0.835            |
| 2025 | 25.182.680,45         | 3.257                | 2.172            | 35.140                        | 1.330                            | 0.887            |
| 2026 | 25.895.562,55         | 3.297                | 2.198            | 36.992                        | 1.406                            | 0.937            |

3.3. Methane emissions from wood waste

Methane emissions from the wood waste sector for 2010-2016 and its prediction from 2017 to 2026 can be seen in Table 6 and Table 7, respectively.

Table 6. Methane emissions from wood waste.

| Year | Waste Generation (kg) | $\text{DDOC}_m$ (Gg) | $\text{Lo}$ (Gg) | $\text{DDOC}_{\text{maT}}$ (Gg) | $\text{DDOC}_{\text{m decompT}}$ (Gg) | $\text{CH}_4$ (Gg) |
|------|-----------------------|----------------------|------------------|-------------------------------|----------------------------------|------------------|
| 2010 | 16.567.273            | 0.187                | 0.125            | 0.187                         | 0.000                            | 0.000            |
| 2011 | 17.038.990            | 0.209                | 0.140            | 0.370                         | 0.004                            | 0.002            |
| 2012 | 19.467.198            | 0.214                | 0.143            | 0.572                         | 0.007                            | 0.005            |
| 2013 | 20.671.459            | 0.260                | 0.174            | 0.775                         | 0.011                            | 0.008            |
| 2014 | 21.232.997            | 0.260                | 0.174            | 1.020                         | 0.016                            | 0.010            |
| 2015 | 20.612.902            | 0.256                | 0.170            | 1.260                         | 0.020                            | 0.014            |
| 2016 | 20.431.477            | 0.247                | 0.165            | 1.491                         | 0.025                            | 0.017            |

Table 7. Prediction of methane emissions from wood waste.

| Year | Waste Generation (kg) | $\text{DDOC}_m$ (Gg) | $\text{Lo}$ (Gg) | $\text{DDOC}_{\text{maT}}$ (Gg) | $\text{DDOC}_{\text{m decompT}}$ (Gg) | $\text{CH}_4$ (Gg) |
|------|-----------------------|----------------------|------------------|-------------------------------|----------------------------------|------------------|
| 2017 | 20.142.565,83         | 0.247                | 0.165            | 1.708                         | 0.030                            | 0.020            |
| 2018 | 20.712.770,21         | 0.250                | 0.167            | 1.921                         | 0.034                            | 0.023            |
| 2019 | 21.299.116,18         | 0.254                | 0.169            | 2.133                         | 0.038                            | 0.026            |
| 2020 | 21.902.060,68         | 0.260                | 0.174            | 2.344                         | 0.043                            | 0.028            |
| 2021 | 22.522.073,59         | 0.264                | 0.176            | 2.557                         | 0.047                            | 0.031            |
| 2022 | 23.159.638,09         | 0.267                | 0.178            | 2.770                         | 0.051                            | 0.034            |
| 2023 | 23.815.251,04         | 0.270                | 0.180            | 2.982                         | 0.055                            | 0.037            |
| 2024 | 24.489.423,37         | 0.274                | 0.183            | 3.192                         | 0.060                            | 0.040            |
| 2025 | 25.182.680,45         | 0.277                | 0.185            | 3.402                         | 0.064                            | 0.043            |
| 2026 | 25.895.562,55         | 0.281                | 0.187            | 3.612                         | 0.068                            | 0.045            |

From Table 2 until Table 7, it can be seen that the prediction of methane emissions from organic, paper, and food waste generation has increased every year. This phenomenon is directly proportional to the number of populations and waste generation where both each year also increases.
4. Conclusions

Based on the research of methane emission estimation in Tamangapa Landfill, the following conclusions can be obtained:

- Methane gas emissions from the existing waste sector in Makassar city in 2016 reached 2,240 Gg generated from 237,851,884 kg of waste generation in 2016, almost all of which operate in open dumping. Most of this gas is produced from the degradation process of paper, wood, and organic waste.

- Prediction of methane gas emissions in Tamangapa Landfill for the next ten years can be seen from the results of data processing predicted until 2026. The prediction of methane emissions (CH4) in 2026, based on solid waste generation data reached 5,047 Gg and based on the amount of population reaching 4,968 Gg. The amount of methane emission each year, both the overall generation of waste and by characteristics, has increased. This phenomenon is influenced by the increasing population from year to year, causing more waste generation, which also causes the generation and emissions of methane. The high potential of methane gas emissions is due to the condition of Tamangapa landfill which is generally 'wet' due to climate and also the composition of organic waste which is almost 60% - 70%.

- Some efforts to mitigate methane emissions can be carried out such as the socialization of 3R techniques (Reduce, Reuse, and Recycle) and the construction of a sanitary landfill to replace the open dumping landfill in Makassar city by the mandate of Law no. 18 of 2008.

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