Study to reduce greenhouse gas emissions at waste landfill in Medan City

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Abstract: Landfill is a place where waste reaches the final stage. The piles of waste can generate greenhouse gas emissions that cause global warming the potential of climate change. The greenhouse gas emission generates from the piles of waste is CH₄ emission. The research purpose is to count CH₄ emission in the waste landfill in Medan city located in Terjun, projection CH₄ emission for ten years later is 2020-2029 and decisive the effort reduction of CH₄ emission. The scenarios of reducing CH₄ emission in Terjun waste landfill reduce the potential CH₄ emission for ten years later. The calculation of CH₄ emission from the piles of waste in Terjun waste landfill using FOD method (First Orde Decay) by IPCC (Intergovernmental Panel on Climate Change) in 2006. In 2019, CH₄ emission in Terjun waste landfill was 12,350.750-ton CH₄ and had an uplift in 2029 can reach 17,143.087-ton CH₄. There are two scenarios for reducing CH₄ emission in the Terjun waste landfill; the first is the processing of waste in the source (composting), and the second is reducing the waste by using incineration technology Terjun landfill. The first scenario (composting) can reduce CH₄ emission by 14.80%. The second scenario can reduce by 63.37% the CH₄ emission in Terjun waste landfill. The chosen alternative scenario for reducing CH₄ in the Terjun waste landfill is the first scenario, the processing of waste in the source (composting).

1. Introduction
The increasing number of residents in Medan also increases the amount of waste generated in Medan. Piles of both organic and inorganic waste will cause the waste to undergo weathering, which triggers greenhouse gas formation, namely CH₄ gas. Every 1 ton of solid waste will produce about 50 kg of methane gas [1]. Based on the 2006 Intergovernmental Panel on Climate Change (IPCC) report, the waste sector also contributes greenhouse gas to the atmosphere, specifically from landfills, contributing between 3 – 4% of global greenhouse gas emissions [2].

Greenhouse gas is a gas in the atmosphere that functions to absorb infrared radiation and determines the atmosphere’s temperature. The existence of various human activities can increase the concentration of greenhouse gas emissions in the atmosphere. It can trigger the problem of global warming and climate change. The generation of CH₄ gas in the landfill usually starts 6-12 months after being placed, increases after the landfill’s closure and gradually decrease over 30-50 years. One ton of domestic waste can produce 300 m³ of biogas. CH₄ gas is one of the main greenhouse gasses against global warming. CH₄ gas concentration in the atmosphere has increased by about 0.6% per year and more than doubled over the last two centuries [3].

The purpose of this study is to calculate the CH₄ gas emissions produced at Terjun Waste Landfill,
projecting the CH$_4$ gas emissions produced by Terjun Waste Landfill for the next ten years and determining the efforts to reduce CH$_4$ gas emissions at Terjun Waste Landfill. Indonesia is committed to reducing greenhouse gas emissions by 26% and 41% if it gets help from abroad. The increasing greenhouse gas emissions in the atmosphere will cause global warming that triggers climate change, so it is necessary to carry out an inventory of greenhouse gas emissions which will produce data on the estimated burden of greenhouse gas emissions which is used as the primary basis in determining efforts to mitigate greenhouse gas emissions.

2. Methodology

2.1. Data collection
The primary data for this research is the characteristics of the waste and the calorific value of the waste. Waste taken in the form of waste aged 27 years, 20 years and ten years at Terjun Waste Landfill to test the characteristics of the waste in the form of physical characteristics of the waste such as water content, volatile content, ash content and calorific value was carried out in the laboratory. The purpose of taking waste aged 10-27 years is so that the results of the characteristic test can represent the characteristics of the waste in Terjun Waste Landfill.

The secondary data of this study is the population of Medan in 1993-2012 obtained from the Central Statistics Agency of Medan. The amount of waste generation for Medan based on the Ministry of Public Works is 0.8 kg/p/day. Waste composition data were obtained from previous studies [4].

2.2. Waste generation projection calculation
The calculation of the projected waste generation at Terjun Waste Landfill is carried out using the formula. The formula for calculating the projected waste generation at Terjun Waste Landfill is [5]:

\[
\text{Amount of projected year waste = Previous year waste} \times (1 + \text{average of waste growth})^{\text{projection year - previous year}}
\]

The average waste growth = \((\text{final value} - \text{initial value})^{\text{growth rate}} - 1\) x 100%

2.3. Calculation of CH$_4$ emissions at Terjun Waste landfills
Calculation of CH$_4$ emissions is carried out based on the provisions of the IPCC [6]. This study uses the FOD (First Order Decay) method. This method is more accurate because it can calculate methane recovery, where methane gas produced from solid waste in the landfill can be used as environmentally friendly energy. The equation used to calculate methane gas emissions in the waste sector at the landfill in this study refers to the 2006 IPCC guidelines.

\[
\begin{align*}
\text{DDOCm rem}_T &= \text{DDOCm} \cdot e^{-k(13-M)/12} \\
\text{DDOCm dec}_T &= \text{DDOCm} \cdot (1 - e^{-k(13-M)/12}) \\
\text{DDOCma}_T &= \text{DDOCm rem}_T + (\text{DDOCma}_T - 1) \cdot e^{-k} \\
\text{CH}_4 \text{ Generated}_T &= \text{DDOCm dec}_T + \text{DDOCma}_T \cdot (1 - e^{-k}) \\
\text{DDOCm} &= \text{W. DOC} \cdot \text{DOCf} \cdot \text{MCF} \\
\text{Emisi CH}_4 &= \left(\sum x \text{ Timbulan CH}_4 \cdot x, T - \text{R}_T\right) \cdot (1 - \text{OX}_T)
\end{align*}
\]

Information:

\[
\begin{align*}
T &= \text{Inventory year} \\
\text{DDOCm remT} &= \text{Mass of DDOCm deposited, which does not decompose in year T that remains until the end of the year (Gg)} \\
\text{DDOCmTd} &= \text{DDOCm at the end of the year (T-1) (Gg)} \\
\text{DDOCm decT} &= \text{DDOCm in year T which has decomposed at the end of year T (Gg)} \\
\text{DDOCmaT} &= \text{DDOCm accumulated in landfill at the end of year T (Gg)}
\end{align*}
\]
DDOCmaT-1 = DDOCm accumulated in the landfill at the end of the year (T-1) (Gg)
DDOCm decompT = DDOCm decomposed in year T (Gg)
M = Month when reaction started, equal to +7 average waiting time (months)
k = Reaction rate constant (y\(^{-1}\))

\(\text{CH}_4\) Generated\(_T\) = \(\text{CH}_4\) formed in year T as a result of the decomposition of organic components that are stored in the trash (DDOC) (Gg)

\(F\) = Fraction of \(\text{CH}_4\) generated in landfill (0,5)

16/12 = \(\text{CH}_4\) / C molecular weight ratio

DDOCm = Mass of DOC which stored in waste in a biodegradable landfill (Gg)

W = Mass dumped garbage (Gg)

DOC = Carbon degraded organic (Gg C/Gg Garbage)

DOCF = Fraction of biodegradable DOC (for Indonesia 0,5)

MCf = \(\text{CH}_4\) correction factor for aerobic decomposition (0,8)

\(R_T\) = Amount of \(\text{CH}_4\) recovered in year T (Gg)

OX = Oxidation factor in year T (Fraction).

Parameters that use IPCC default numbers are oxidation factor (OX) and DOC (Degradable Organic Carbon) data.

3. Results and discussion

3.1. Waste generation at Terjun Waste Landfill

There is no data on waste generation at Terjun waste landfill from the beginning of the operating year until 2012. It was because there were no scales at that time and the administrative system at Terjun Waste Landfill was also not adequate. In 2013, we started weighing the waste transported by trucks that enter the waste landfill. Every truck that enters will be recorded first before entering the waste landfill. The amount of waste generated at Terjun Waste Landfill in 1993-2019 can be seen in Figure 1.

Figure 1. Waste generation (tons) at the Terjun Waste Landfill in 1993-2019.
3.2. Projection of waste generation at Terjun Waste Landfill

Projection of waste generation can be seen in Figure 2.

![Figure 2. Projection of waste generation (tons) at Terjun Waste Landfill.](image)

Based on Figure 2, waste generation always increases every year. With the increasing number of residents in Medan, more waste in Medan will be disposed of to the Terjun waste landfill. The percentage increase in waste generation from 2020-2029 is 7.79%. The amount of waste generated by a city is primarily determined by all community activities in that city. These activities include trading activities, housing, offices, industrial activities, agriculture and others. One of the things that affect the waste generation in a city is the number and density of the population. The amount of waste generated is directly proportional to the population. The more the population, the more waste generated. Likewise, for population density [7].

Other factors influence waste generation apart from a large number of residents. The level of income of the population affects the generation of waste in Bukittinggi. Residents with high incomes (HI) generate higher waste than people with middle and low incomes (LI). Waste generation for high-income residents produces 0.28 kg/person/day, middle-income residents generate 0.22 kg/person/day and waste generation generated by low-income residents produces 0.10 kg/person/day. It is because people with high incomes (HI) do more activities that produce waste. The method of handling waste by high-income residents is different from that of low-income residents. Residents with high incomes (HI) usually throw away what is no longer needed. In comparison, people with low incomes (LI) can still use the waste they produce, such as food waste used for animal feed or yard waste used as fertilizer [8]. The amount of generation is directly proportional to community life. The higher the level of life, the greater the generation of waste [9].

3.3. CH₄ emissions at Terjun Waste Landfill

The calculation of CH₄ emissions begins with calculating the year the Terjun waste landfill started operating. In 1993, the CH₄ emission in the Terjun waste landfill was 0 tons. It took 13 months to produce the CH₄ anaerobic process from the waste heap in the waste landfill. Methane gas is formed from the anaerobic decomposition of organic matter by methane bacteria (methanogens). The aerobic decomposition process lasts for approximately 2-3 weeks until the oxygen supply in the waste is reduced. After the O₂ gas is exhausted, it is followed by anaerobic acid decomposition. Anaerobic bacteria produce CO₂ and organic acids. This process occurs for 1-2 years, and the temperature of the waste has decreased. Furthermore, the decomposition process enters the final stage, namely anaerobic methane. In this process, the bacteria produce CH₄ and CO₂ [10].
After calculating CH$_4$ emissions at Terjun Waste Landfill from the beginning of operations until 2019, a projected CH$_4$ emission calculation is carried out for the next ten years. The calculation is also the same as the previous calculation of CH$_4$ emissions. The following is an example of calculating CH$_4$ emissions at the Terjun Waste Landfill in 2020. Total Terjun waste landfill emissions from 1993 to 2029 can be seen in Figure 4.

Based on Figure 4, the amount of CH$_4$ emissions produced by the waste at Terjun Waste Landfill in 1993 was 0 tons of CH$_4$. It took 13 months for the formation of CH$_4$ from the waste heap. Therefore, CH$_4$ emissions in 1994 amounted to 1,145.438 tons of CH$_4$ or 28,635.947 tons of CO$_2$e. In 2014, CH$_4$ emissions at Terjun Waste Landfill experienced a significant increase, amounting to 8,862.141 tons of CH$_4$ or 221,553.13 tons of CO$_2$e. The amount of waste that went to Terjun Waste Landfill in 2013 increased after Namo Bintang Waste landfill was officially closed. The increase in the amount of CH$_4$ emissions is due to the increasing amount of waste generation.
Terjun Waste Landfill still uses an open dumping system and has more than 10 meters of waste thickness. The magnitude of the potential for CH$_4$ gas produced at the waste landfill is not only influenced by the increase in waste generation. The thickness of the waste also affects the formation of CH$_4$ through air access and the density of the waste. Open dumping waste landfill system with a thickness of > 5 meters of waste, more CH$_4$ gas production due to the upper layer of waste preventing air access from entering the lower layer and creating anaerobic conditions so that more CH$_4$ gas is produced [11].

The composition of the waste also affects the production of CH$_4$ gas in waste landfills. The more organic waste there is, bacteria decompose, producing more gas [12]. The composition of the waste will determine the nutrient content that has a vital role in gas formation. Organic waste disposed of in waste landfills is the most significant factor affecting the quality of gas emissions because it contains organic carbon that is easily degraded [13].

3.4. CH$_4$ emission reduction scenarios

3.4.1. Waste treatment at source (composting). In this scenario, the data needed is the number of residents of Medan who are willing to do composting and the amount of organic waste that is reduced to compost. Based on the questionnaire results, only 58% of the residents of Medan are willing to sort their waste at the source (composting).

The reduction in organic waste that is processed by aerobic composting is 40%-60% [14]. The reduced waste in this scenario is organic in food waste and leaf/garden waste. The percentage of waste reduction in this scenario is 60%. The amount of waste that was reduced at Terjun Waste Landfill due to composting was 26.61%. Next, calculate CH$_4$ emissions from waste that is not composted and disposed of at Terjun Waste Landfill. The purpose of calculating CH$_4$ emissions from the waste is to find out how much CH$_4$ emissions are after composting activities at the source. The calculation of CH$_4$ emissions is similar to baseline CH$_4$ emissions, but the difference is the amount of waste reduced because it has been reduced from the source. The comparison of CH$_4$ emissions in Terjun waste landfill before and after composting can be seen in Figure 5.

![Figure 5. Comparison of the amount of CH$_4$ emissions (tons of CH$_4$) before and after composting at the source in 2020-2029.](image-url)

Based on Figure 5, the number of emissions at Terjun Waste Landfill will decrease if composting is carried out at the source. It is due to the reduction of organic waste every year. In Figure 5, the CH$_4$ emissions in 2020 before composting was 12,545.413 tons of CH$_4$ or equivalent to 313,635.322 tons of...
CO$_2$e. After composting, it became 11,840.284 tons of CH$_4$ or equivalent to 296,007.097 tons of CO$_2$e. The per cent reduction in CH$_4$ emissions from 2020-2029 with composting at the source is 14.80%. If there is an increase in the willingness of the residents of Medan to do composting at the source every year, then the amount of reduced waste will increase, and the percentage of CH$_4$ reduction can also increase every year.

Processing of waste by composting will reduce CH$_4$ emissions. Without processing, organic material in a waste landfill will produce CH$_4$ emissions of 2,326,007 tons/year. Meanwhile, with composting activities, CH$_4$ emissions are reduced to 9,255-18,344 kg/year. Indonesia's experience in reducing CH$_4$ emissions from composting activities carried out by the World Bank through the Compost Subsidy Program in 2004-2005 in 16 cities in the western part of the island of Java which succeeded in reducing CH$_4$ emissions by 11,049-14,916 m$^3$ or equivalent to 254,129-343,074 tons of CO$_2$ [15].

Composting 1.9 tons of waste can produce 1 ton of compost, while one ton of waste is stored in a landfill can produce 0.20-0.27 m$^3$ of CH$_4$ emissions. Thus, producing 1 ton of compost can reduce CH$_4$ emissions by 0.21-0.29 tons of CH$_4$ or equivalent to 5-7 tons of CO$_2$e [16].

3.4.2. Waste reduction with incineration technology at Terjun Waste Landfill. The results of testing the calorific value of Terjun waste landfill are very high, namely 12,009.834.67 kJ/kg. The usefulness of knowing the calorific value of waste is to find out whether the waste is good or not if it is managed by incineration. Waste can be processed by incinerator without the need for additional fuel with a minimum calorific value of 2,200 kcal/kg or the equivalent of 9,196 kJ/kg [17]. Various studies state that the calorific value required for WtE from the incineration process whose energy will later be utilized is 7,000 kJ/kg or more and should not be below 6,000 kJ/kg [18]. Therefore, the waste in Terjun Waste Landfill is very suitable if it is managed by incineration because it has a very high calorific value. The process of processing waste by incineration can reduce waste by 80%-90% [19]. In this scenario, the reduction of waste by incinerator is 90%. The comparison of CH$_4$ emissions before and after the waste is processed by the incinerator can be seen in Figure 6.

![Figure 6](image_url)

**Figure 6.** Comparison of the amount of CH$_4$ emissions before and after the waste is reduced by the incinerator in 2020-2029.

Figure 6 shows the amount of CH$_4$ emissions in 2020 before the waste reduction with the incinerator was 12,545.413 tons of CH$_4$ or equivalent to 313,635.322 tons of CO$_2$e, but after the incinerator reduced the waste, it became 9,526.192 tons of CH$_4$ or equivalent to 238,154.800 tons of CO$_2$e. The percentage of CH$_4$ emission reduction from 2019-2028 by reducing waste with an incinerator is also 63.37%.
Incineration technology is very feasible at Terjun Waste Landfill because, in terms of the characteristics and calorific value of the waste, it is very feasible to be managed by the incineration process.

3.4.3. **Alternative scenario.** After obtaining the total CH$_4$ emissions from each scenario, the magnitude of the CH$_4$ emissions reduction can be known. The graph of the reduction of CH$_4$ emissions at Terjun Waste Landfill in 2020-2029 can be seen in Figure 7.

![Figure 7](image)

**Figure 7.** Graph of CH$_4$ emission reduction in Terjun Waste Landfill in 2019-2029.

Based on Figure 7, the most significant reduction in CH$_4$ emissions is in scenario 2, namely incineration technology. Incineration technology can reduce waste, a source of CH$_4$ emissions in Terjun Waste Landfill, using an incinerator by 63.37% so that the CH$_4$ emissions in Terjun waste landfill are reduced a lot. Besides reducing waste, the steam produced from burning waste using an incinerator can be used as renewable energy. However, from an environmental point of view, it is also dangerous because incinerators are feared to cause air pollution gases that endanger human health and the environment if the temperature is not optimal when operating. The use of this incinerator also requires a huge investment cost, requires a large area of land, and its operation is not easy; it must be maintained.

In scenario 1, composting can only reduce CH$_4$ emissions at Terjun Waste Landfill from 2020-2029 by 14.80%. At least the reduction of CH$_4$ emissions in Terjun Waste Landfill from composting activities is caused by several factors. First, every year the amount of waste is increasing, but the willingness of the residents of Medan to do composting at home is not too much, only 58%. If the population's willingness to do composting increases every year, it is possible that the reduced amount of CH$_4$ emissions in the Terjun Waste Landfill could continue to increase. Second, not all the waste used as compost can be composted, only food waste and garden/garden waste. However, not all food waste and garden/garden waste can be composted. Only 40%-60% of the waste can be processed into compost.

Based on the description above, the alternative scenario chosen to reduce CH$_4$ emissions in Terjun Waste Landfill in the next ten years is scenario 1, namely processing waste at the source (composting). The selection of this scenario is assessed based on the impact on environmental quality, land requirements, investment costs, and operation.

4. **Conclusion**

The amount of CH$_4$ emissions produced at Terjun Waste Landfill in 1994 was 1,145,438 tons of CH$_4$, or equivalent to 28,635,947 tons of CO$_2$e from the total waste of 34.978 Gg. In 2019 the CH$_4$ emissions
increased to 12,350,750 tons of CH$_4$ or equivalent to 308,768,750 tons of CO$_2$e from a total waste of 367,569 Gg. Projected CH$_4$ emissions produced by Terjun Waste Landfill in the next ten years continue to increase. By 2029 emissions of CH$_4$ reach 17,143,087 tons of CH$_4$ or equivalent to 428,577,177 tons of CO$_2$e from the total waste of 544,092 Gg. Efforts to reduce CH$_4$ emissions in the waste sector at Terjun Waste Landfill by processing waste at the source (composting) and reducing waste with incineration technology at Terjun Waste Landfill. In 2029, scenario 1 (composting) can reduce CH$_4$ emissions in Terjun Waste Landfill to 13,188,749 tons of CH$_4$ or equivalent to 347,187,828 tons of CO$_2$e. The percentage of CH$_4$ emission reduction in 2019-2028 from composting activities is 14.80%. Meanwhile, scenario 2 (waste reduction with an incinerator) can reduce CH$_4$ gas emissions at Terjun Waste Landfill in 2029 to 3,203,280 tons of CH$_4$ or equivalent to 80,081,991 tons of CO$_2$e. The percentage of CH$_4$ emission reduction in 2020-2028 from waste reduction with incinerator is 63.37%.

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