Technical and Economic Analysis of Municipal Solid Waste Potential for Waste to Energy Plant (Case Study: Jatibarang Landfill Semarang, Central Java, Indonesia)

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Abstract. Municipal solid waste (MSW) is still a serious problem in Indonesia. As well as following up on the Indonesian Government’s commitment to reduce carbon emissions, a Presidential decree Perpres Number 18 of 2016 concerning the Acceleration of the Development of Waste-Based Power Plants was made. It is expected that the construction of Waste-Based Power Plants from landfills can reduce the budget deficit in handling municipal waste while maintaining environmental preservation. This research calculates the potential of landfill gas that can be produced from the landfill waste dumps of Jatibarang, as well as the capacity of electrical energy that can be produced. Furthermore, with several types of plant scenarios used, it can be seen the economic feasibility of the construction of a Waste Based Power Plant in Jatibarang landfill. The landfill gas potential and economic feasibility for this study are calculated using the Intergovernmental Panel on Climate Change (IPCC) Inventory Software and LFG-CostWeb from LandGEM. The results showed that only from the electricity sale Standard Reciprocating Engine-Generator Set project may generate a break even in the 6 yr after the operation begins and value of the net present value is USD 755,664 for 15 yr project lifetime.

Keywords: Green, landfill gas, renewable energy, urban waste, waste-based power plant, waste management

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1 Introduction

One of the real consequences of population growth and the rapid increase in activity in big cities is the increasing amount of waste. The general paradigm encountered to date in waste management in cities—cities in Indonesia is gathering-transport-waste. Moreover, along with population growth, the amount of waste that must be handled will increase. The budget deficit in handling municipal waste is one of the factors that makes waste management think in the future in efforts to develop waste [1]. National waste sources are still dominated by domestic sources, according to the data of the Ministry of Environment [2], which is shown in Figure 1.

![Fig. 1. National waste sources.](image1.png)

Meanwhile, the national waste composition, still dominated by the organic components of 60% are shown in Figure 2.

![Fig. 2. National waste composition.](image2.png)

Of all the existing waste, generally in the landfill, while the waste that is managed either in the form of compost, biogas, recycling of raw materials, etc. is still around 15%, even lower than the amount of unmanaged waste, which reaches almost 20%. Data on the percentage of waste processing is shown in Figure 3.
Similar to the national condition, the waste component in the cities of Central Java is also dominated by around 60% organic component, the organic waste has a big opportunity to be further processed either as a basic material for compost or as a biogas producer that can be utilized as a new energy source [3]. Approximately 60% of dominance of organic matter in Indonesia is similar with Malaysia based on Khariri et al. [4] Also, it has explained the negative impact of municipal solid waste landfill on human health.

One program that is expected to be able to solve the problem of garbage in urban areas is Waste to Energy Power Plant or Pembangkit Listrik Tenaga Sampah (PLTSa). Related to this PLTSa regulation, it has been stated in Presidential Regulation No. 18 of 2016 concerning the Acceleration of Development of Waste Based Power Plants. The Presidential Regulation states that there are seven cities as pilot projects, namely Jakarta, Tangerang, Bandung, Semarang, Surakarta, Surabaya, and Makassar. Based on this perspective, the conversion of municipal solid waste into energy has a great opportunity, in terms of reducing the volume of waste and increasing the production of alternative fuels, while reducing carbon emissions.

![Percentage of waste processing](image)

**Fig. 3.** Percentage of waste processing.

The Jatibarang Landfill (TPA) is owned by the Semarang City Government and is operated by the UPPD TPA DKP Semarang. This landfill has been operating since 1992, and it is not known exactly how long this landfill will be used. The Jatibarang landfill currently receives 800 t d⁻¹ of garbage from the city of Semarang. Until now, according to available data, it is estimated that at least about $3.5 \times 10^6$ t of waste is stored in the landfill. Waste dumps on the Jatibarang landfill have an energy potential that arises in the form of carbon content in waste, and one of the direct forms is biogas produced from organic waste. As the only landfill in the city of Semarang, the Jatibarang landfills has a variety of energy potentials, which, if utilized further, will have a positive impact on the environment and city residents.

Research on waste power generation has been carried out in various countries, including Indonesia. The potential of biogas from sanitary landfills and the use of biogas from Bellville South Municipal Landfill (Cape Town, South Africa) was examined to become
primary energy in the region. It was stated in the study that the cost of producing electricity from biogas is expected to be cheaper than the current tariff of around 35 %. These figures are based on the presence of ready-to-use gas, assuming a similar investment in production [5]. An analysis has been carried out on the use of thermal converter technology in waste processing at the Denpasar Suwung landfill, Indonesia using organic waste as fuel to produce superheated steam used to turn turbines [6]. From the results of research conducted, with a capacity of 204 t of dry solid waste supplied by Sarbagita Sanitation Management Agency (BPKS), and assuming a generator efficiency of 30 % power output of around 4.128 MW to 4.581 MW can be generated. The change from processing organic waste into the industrial scale in several animal husbandry areas in Iran allows the potential for electrical energy of 5.9 MW, 58.8 m³ of liquid compost, and 11 t h⁻¹ of dry compost [7]. One of the technologies in PLTSa is the use of Gas Engines such as SST-050 from Siemens. This Gas Engine Technology is very suitable for use in Bantar Gebang Landfill (Bekasi, Indonesia) due to lower construction costs, and the volume of waste that is converted to more electrical energy, also faster energy conversion processes, and requires less land for construction [8]. Various project analysis of waste power generation projects is done by Intergovernmental Panel on Climate Change (IPCC) and LandGEM software, and is able to produce good estimation values [9–11]. Although biogas from landfills has proven to be able to produce electricity, there are challenges such as those in Brazil, both in terms of technology, and politics, but in general socio-economic support for the use of biogas from landfill is very good due to the potential for environmental improvement and employment opening [12]. The purpose of this research is to calculate the potential of landfill gas that can be generated from the dump of the landfill in Jatibarang Semarang City. It also calculates the capacity of electrical energy that can be generated from the landfill gas reservoirs of the Semarang City Goods Landfill. As well as conducting an economic feasibility study (Feasibility Study) on the use of landfill gas as an alternative electricity generation.

2 Methodology

2.1 Landfill gas (LFG)

Municipal solid waste (MSW) is a waste collected in urban areas. In Indonesia, a waste classification that is often used is organic waste or wet waste, which consists of leaves, wood, leftover fodder, vegetables, fruit, and others. Furthermore, inorganic waste or dry waste, consisting of cans, plastic, iron, and other metals, glass, and mica. Garbage can change the decomposition in two ways, namely biochemistry and physics. The decomposition of organic waste will occur by itself caused by decomposing bacteria. In contrast, inorganic waste and B3 can be decomposed through further actions such as burning classified according to the type of decomposition [1]. Landfill gas (LFG) is a gas produced from the fermentation or anaerobic process of organic materials, such as human waste, animal waste, domestic waste (household), agricultural waste, farm waste, etc. The most important content in LFG is methane (CH₄) and carbon dioxide (CO₂) [13]. The percentage of LFG constituent gas can be seen in Table 1 [14].

Table 1 shows the percentage of gas making up the LFG, and it is seen that the most significant gas content contained in LFG is methane by 50 % to 70 % and followed by carbon dioxide by 30 % to 40 %. Both methane gas and carbon dioxide have a role in increasing global warming and are categorized as greenhouse gas (GHG). Landfill gas
produced at landfills will be dangerous if not managed and controlled properly. The methane gas content in the LFG is a flammable gas, so the risk of an explosion occurring around the landfill site is very high. IPCC [15] states that the effect of methane gas on increasing global warming is 21 times greater than carbon dioxide. The process of flaring and methane gas extraction can be done as an effort to reduce methane gas emissions and convert it to \( \text{CO}_2 \).

### Table 1. LFG gas composition.

| LFG composition       | Chemical formula | Percentage (%) |
|-----------------------|------------------|----------------|
| Methane               | \( \text{CH}_4 \) | 50 to 70       |
| Carbon dioxide        | \( \text{CO}_2 \) | 30 to 40       |
| Hydrogen              | \( \text{H}_2 \)  | 5 to 10        |
| Nitrogen              | \( \text{N}_2 \)  | 1 to 2         |
| Dinitrogen oxide      | \( \text{N}_2\text{O} \) | 0.3          |
| Hydrogen Sulfide      | \( \text{H}_2\text{S} \) | very few      |

To find out the gas production produced from landfill, the calculation can be used based on the first-order decay method of IPCC, where the activity data used is data that has a high degree of accuracy because it is surveyed directly from the relevant landfill. It aims to improve the quality of GHG emission calculations; however, standard methods for several emission factors are still used. To calculate the potential of Methane Gas in a landfill gas contained in the landfill, the following Equation is used [16]:

\[
L_o = DDOC_M \cdot F \cdot \left( \frac{16}{12} \right)
\]

where,
- \( L_o \) = methane production potential (Gg)
- \( DDOC_M \) = DOC mass that can be composed (Gg)
- \( F \) = fraction of methane

Moreover, to calculate the amount of \( DDOC_m \), we need data on the amount of waste contained in a landfill and calculated with the following Equation:

\[
DDOC_M = W \cdot DOC \cdot DOC_F \cdot MCF
\]

where,
- \( W \) = total waste (Gg)
- \( DOC \) = Degradable Organic Carbon
- \( DOC_F \) = fraction of DOC values that can be composed
- \( MCF \) = methane correction factor

Furthermore, to calculate the capacity of electrical energy that can be generated from landfills can be used in Table 2.

### Table 2. Energy conversion.

| Energy type           | Equivalent energy |
|-----------------------|-------------------|
| 1 Kg Methane Gas      | \( 6.13 \times 10^7 \) J |
| 1 kWh                 | \( 3.6 \times 10^6 \) J |
| 1 m\(^3\) Methane Gas | \( 4.0213 \times 10^7 \) J |
2.2 TPA Jatibarang Semarang

_Tempat Pembuangan Akhir_ (TPA) or the landfill of Jatibarang is located about 12 km southwest of the center of Semarang City. The total area of this place is 40 ha, of which around 9 ha of the area has been used or filled with garbage. This place is hilly with steep slopes. The available land is no more than about 22 ha, including the current active area and an area that has been filled with garbage. A river surrounds part of this landfill, flowing along the southern border of the landfill to the east (Figure 4).

![Aerial image of Jatibarang Landfill area, Semarang.](image)

**Fig. 4.** Aerial image of Jatibarang Landfill area, Semarang.

### Table 3. Weighbridge data of TPA Jatibarang 2016

| Month       | Waste input (t mo⁻¹) | t d⁻¹ |
|-------------|----------------------|-------|
| January     | 18 092               | 584   |
| February    | 22 321               | 770   |
| March       | 23 362               | 754   |
| April       | 23 561               | 785   |
| May         | 24 882               | 803   |
| June        | 23 943               | 798   |
| July        | 22 961               | 741   |
| August      | 23 195               | 748   |
| September   | 24 805               | 827   |
| October     | 26 194               | 845   |
| November    | 26 223               | 846   |
| December    | 26 748               | 863   |
| 2016        | 286 287              |       |
| average     | 23 857               | 784   |

This landfill is owned and operated by the City of Semarang (PEMKOT Kota Semarang) and is run by the Department of Environment (DLH) of the City of Semarang. This landfill has been operating since 1993. This landfill has three zones, namely active zone 1 and zone 2, where waste has been stockpiled until the end of 2017, and the third zone, previously used as a reserve, but now used as an active zone. The area for zone 1 is around 27 700 m², and zone 2 is around 35 800 m². There is a leachate collection network...
that channels the leachate to a processing facility located at the southern end of the location and can be accessed from the access road. There is also a pump housing with a small generator set and several pumps. Leachate is processed by combining anaerobic and aerobic processes. There are several aerators that are operated in an aerobic pool. Jatibarang landfill is the final landfill in Semarang. At present, the facility receives around 780 t d⁻¹ to 800 t d⁻¹ of waste. According to information available from DLH, there is no industrial waste or B3 waste dumped into the landfill, but this has not been verified. Taking into account the amount of waste recorded per year entering the landfill and the estimated lifetime of the landfill, it can be calculated that a total of around $3.5 \times 10^6$ t of waste has been piled up to date. Table 4 shows the average ton of waste received at the landfill each day.

| Year | t d⁻¹ |
|------|-------|
| 1999 | 575   |
| 2000 | 578   |
| 2001 | 582   |
| 2002 | 585   |
| 2003 | 590   |
| 2004 | 597   |
| 2005 | 603   |
| 2006 | 606   |
| 2007 | 609   |
| 2008 | 610   |
| 2009 | 614   |
| 2010 | 620   |
| 2011 | 625   |
| 2012 | 675   |
| 2013 | 750   |
| 2014 | 800   |
| 2015 | 800   |
| 2016 | 800   |
| 2017 | 800   |

Fig. 5. Waste composition in Jatibarang Landfill, Semarang.
The operator of landfills also has data on the composition of waste. From this composition, food waste reached 43.36% of stored waste, followed by garden waste at 18.58%. Plastic and other impurities are 13.4%, while the paper is at 12.26%. The rest is in the form of wood, cloth, diapers, and other waste. The pie chart in Figure 5 explains the composition of the incoming waste.

Landfill operations are equipped with the use of heavy equipment. Heavy equipment includes bulldozers, excavators, wheel loaders and dumper trucks. These tools are owned by the operator, and it is believed that if the machines are used in full they can meet proper governance at the landfill.

2.3 IPCC inventory software

The Inter-Governmental Panel on Climate Change (IPCC) is a scientific panel consisting of scientists from all over the world. The IPCC was established in 1988 by two UN organizations, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to evaluate the risks of climate change due to human activities, by examining all aspects based on the technical/scientific literature that has been reviewed and published. Besides actively carrying out various activities, IPCC also makes devices that help researchers around the world, one of which is to calculate GHG emissions, namely IPCC Inventory Software, these devices are made based on the methodology that has been studied and developed in the IPCC panel to calculate various GHG emission products including methane gas [17]. The initial view of the IPCC Inventory Software is shown in Figure 6.

![Fig. 6. The initial view of IPCC inventory software.](image)

The display in Figure 6 shows the first process of making a superuser that has full access to the application and the data contained therein. In this research, IPCC Inventory Software is used to determine the value of L₀ (Equation 1), which will be used as input in LFGCost-WEB software. The value of L₀ in LFGCost-WEB software is in (ft³ t⁻¹) unit while the IPCC software is in Gg (t) unit, so a conversion must be made. The use of IPCC
Inventory Software is to ensure the accuracy of calculation and analysis. The parameter value used in this research on IPCC Inventory Software is shown in Table 5.

Basically, Jatibaran landfills can be categorized as Managed-Semi Aerobic landfills, but in practice, there are local farmers who tend cattle in the landfill area, as shown in Figure 7. To compensate for the uncertainty factor in this study, the Jatibaran landfill is categorized as an unmanaged landfill. In IPCC Inventory Software, the unmanaged category for landfills with a waste depth of more than 5 m, such as Jatibaran, is included in the unmanaged-deep category that affects the value of MCF (Methane Correction Factor) is equal to 0.8.

Table 5. IPCC inventory software parameter

| Parameter                  | Set value          | Remark                   |
|----------------------------|--------------------|--------------------------|
| Region                     | Asia-South-East    |                          |
| Starting year              | 1999               |                          |
| Climate zone               | Tropical wet       |                          |
| DOC (Degradable organic carbon) | -                | default IPCC              |
| MCF (Methane correction factor) | 0.8               | Unmanaged deep           |
| Approach                   | Waste by composition | Figure 5                |
| Activity data              | National data      | TPA Jatibaran operator   |

Fig. 7. Group of cows in TPA Jatibaran.

2.4 LFGCost-Web (landfill gas energy cost model)

LFGCost-Web is a spreadsheet tool built by Environmental Protection Energy (EPA) in the Landfill Methane Outreach Program (LMOP) program. This tool provides an estimate of the potential LFG, especially methane gas, which can be used as a source of electrical energy, also calculates an economic analysis of the construction of an LFG treatment system based on the type of project to be built [18]. The initial view of the software is shown in Figure 8.

This study uses two funding scenarios on the basis that the construction of waste to energy power plants in the Jatibaran Landfill is a pilot project of the Government of Indonesia. It is assumed that in the first scenario, 80% of the project value will be funded by the government, while in the second scenario, the project will get a flat grant of
USD 3 000 000. Then the scenario will be used to build three types of energy projects. The use of scenarios in this study is shown in Table 6.

![Image of LFGCost-Web software](image)

**Fig. 8.** Initial view of LFGCost-Web (landfill gas energy cost model) software.

**Table 6.** Research scenario.

| Scenario   | Government fund     | Project types                                           |
|------------|---------------------|---------------------------------------------------------|
| Scenario 1 | 80 % of the project | Small Engine Generator Set                              |
|            |                     | Standard Reciprocating Engine-Generator Set             |
|            |                     | CHP Reciprocating Engine-Generator Set                  |
| Scenario 2 | Grant of USD 3 000 000 | Small Engine Generator Set                              |
|            |                     | Standard Reciprocating Engine-Generator Set             |
|            |                     | CHP Reciprocating Engine-Generator Set                  |

The scenario will result in different value of parameter ‘Construction grants’ in the software, while the other parameter value will be the same for two scenarios. The other parameter value used in this research on LFGCost-Web Software is shown in Table 7.

**Table 7.** IPCC Inventory software parameter.

| Parameter                                             | Set value | Remark                        |
|-------------------------------------------------------|-----------|-------------------------------|
| Year landfill opened                                  | 1999      | TPA Jatibarang operator       |
| Year of landfill closure                              | 2017      | Based on Scenario             |
| Area of LFG wellfield to supply project (acres)       | 22        | Based on Scenario             |
| Annual waste disposal history                         | Based on the data | TPA Jatibarang operator       |
| LFG energy project type                               | Small engine, Standard Engine, CHP Engine | Based on Scenario |

Table 7. continue to the next page.
The goal of an LFG energy project is to convert LFG into a useful form of energy. In the LFGCostweb software, several project options for the processing of landfill gas into electrical energy are shown in Table 8.
Table 8. LFG energy project type and recommended project size.

| LFG energy project type                                      | Recommended project size                      |
|--------------------------------------------------------------|------------------------------------------------|
| Direct-use (Boiler, Greenhouse, etc.)                        | 400 ft³ min⁻¹ to 3,000 ft³ min⁻¹ LFG           |
| Boiler Retrofit                                              | ≤ 3,000 ft³ min⁻¹ LFG                          |
| High Btu Processing Plant                                    | 1,000 ft³ min⁻¹ to 10,000 ft³ min⁻¹ LFG        |
| Onsite CNG Production and Fueling Station                    | 50 ft³ min⁻¹ to 600 ft³ min⁻¹ LFG              |
| Leachate Evaporators                                         | ≥ 5,000 gallons leachate per day               |
| Standard Turbine-Generator Sets                              | > 3 MW                                        |
| Standard Reciprocating Engine-Generator Sets                 | ≥ 800 kW                                       |
| Microturbine-Generator Sets                                  | 30 kW to 750 kW                               |
| Small Reciprocating Engine-Generator Sets                    | 100 kW to 1 MW                                |
| CHP Reciprocating Engine-Generator Sets                      | ≥ 800 kW                                       |
| CHP Turbine-Generator Sets                                   | > 3 MW                                        |
| CHP Microturbine-Generator Sets                              | 30 kW to 300 kW                               |

3 Result and discussions

3.1 Methane generation rate

As mentioned in section 2, the L₀ value calculation is performed using the IPCC Inventory software to make it more accurate, the value will be used as an input value in the LFGCostWeb software. Calculations with IPCC Inventory software will produce L₀ values in t, then converted to volume units (ft³) based on the density of methane gas. The results of the conversion will be compared with the total amount of garbage from the landfill waste data (approximated 4,532,935 t) so that the L₀ value is in units of ft³ t⁻¹ according to the input requirements in the LFGCostWeb software. The results of calculating the value of L₀ on the IPCC are shown in Figure 9.

Fig. 9. The initial view of LFGCost-Web (landfill gas energy cost model) software.
Based on the IPCC Inventory Software calculation we may generate 180 660 t of methane from a total of 4 532 935 t of waste in the Jatibarang Landfill. With the value of methane gas density = 0.656 kg m\(^{-3}\) [19], we may then convert the L\(_0\) value to 2 146 ft\(^3\) t\(^{-1}\). The value of 2 146 ft\(^3\) t\(^{-1}\) can be input to LFGCostWeb software.

### 3.2 Small engine generator set

From the data obtained, the results of the technical and economic calculations for Small Engine Generator Set project scenarios are shown in Table 9.

**Table 9.** Results of the technical and economic calculations for Small Engine Generator Set project

| Scenario   | Total capital cost | Generating electricity capacity (kW) | Years to breakeven | Net present value |
|------------|--------------------|--------------------------------------|---------------------|-------------------|
| Scenario 1 | USD 3 327 088      | 914                                  | -                   | USD 250 358       |
| Scenario 2 | USD 3 327 088      | 914                                  | 10                  | USD 62 910        |

### 3.3 Standard reciprocating engine-generator set

From the data obtained, the results of the technical and economic calculations for Standard Reciprocating Engine-Generator Set project scenarios are shown in Table 10.

**Table 10.** Results of the technical and economic calculations for Standard Reciprocating Engine-Generator Set

| Scenario   | Total capital cost | Generating electricity capacity (kW) | Years to breakeven | Net present value |
|------------|--------------------|--------------------------------------|---------------------|-------------------|
| Scenario 1 | USD 4 338 261      | 1.48                                 | 6                   | USD 755 664       |
| Scenario 2 | USD 4 338 261      | 1.48                                 | 10                  | USD 319 916       |

### 3.4 CHP reciprocating engine-generator set

From the data obtained, the results of the technical and economic calculations for CHP Reciprocating Engine-Generator Set project scenarios are shown in Table 11.

**Table 11.** Results of the technical and economic calculations for CHP reciprocating engine-generator set.

| Scenario   | Total capital cost | Generating electricity capacity (kW) | Years to breakeven | Net present value |
|------------|--------------------|--------------------------------------|---------------------|-------------------|
| Scenario 1 | USD 5 901 006      | 1.48                                 | 4                   | USD 2 184 765     |
| Scenario 2 | USD 5 901 006      | 1.48                                 | 11                  | USD 591 427       |
4 Conclusion

From the results of the economic feasibility calculation using the LFGCostWeb software, it was found that for scenario 1, with 80% of project financing by the CHP Reciprocating Engine-Generator, Set project country produced the largest NPV and the fastest duration of break-even. Likewise, for scenario two with a USD 3 000 000 flat project financing by the state, the CHP Reciprocating Engine-Generator Set project also generates the largest NPV value, with a margin of more than USD 200 000 compared to the Standard Reciprocating Engine-Generator Set project, but in terms of project break-even time Standard Reciprocating Engine-Generator Set and Small Engine Generator Set 1 yr faster than the CHP Reciprocating Engine-Generator project. Even though the CHP Reciprocating Engine-Generator project looks the most feasible, what needs to be noted is the high cost of project installation. Then, the big profits from this project would be obtained by selling products in the form of steam or hot water. Steam or hot water is a popular product in developed countries with sub-tropical climates, whereas in Indonesia the product itself is minimal in consumers. From these notes, the Standard Reciprocating Engine-Generator Set project is still the most possible. However, if the funds owned by the central and regional governments are limited, the use of Small Engine Generator Set with scenario two still has project feasibility. To produce a more accurate feasibility study, further analysis can be carried out on parameters in the reduction of waste and landfill gas (LFG) models including parameters such as Degradable Organic Carbon mass that can be composed (DDOCm) or Methane generation rate constant (k).

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