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

Mohammad Soleh[1,*], *Hadiyanto* Hadiyanto[2], *Jaka* Windarta[1], *Olga* Anne[3], *Roy* Hendroko Setyobudi[4,5], and *Maizirwan* Mel[6]

[1]Master Program of Energy, Diponegoro University, Jl. Prof. Sudarto No.13, Semarang 50275, Central Java, Indonesia
[2]Faculty of Chemical Engineering, Diponegoro University, Jl. Prof. Sudarto No.13, Semarang 50275, Central Java, Indonesia
[3]Engineering Department of Marine Technology and Natural Sciences Faculty, Klaipeda University H. Manto g. 84, Klaipėda 92294, Lithuania, EU.
[4]Indonesian Renewable Energy Society (METI), Menara MTH Lt, 10 Jalan. MT. Haryono Kav. 23, Center Jakarta 12820, Indonesia
[5]Waste Laboratory - University of Muhammadiyah Malang, Jl Raya Tlogomas No. 246, Malang 65144, East Java, Indonesia
[6]Department of Biotechnology Engineering, International Islamic University Malaysia, Jl. Gombak, 53100, Selangor, Malaysia

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

*Corresponding author: bang.mohsaleh2019@gmail.com

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.

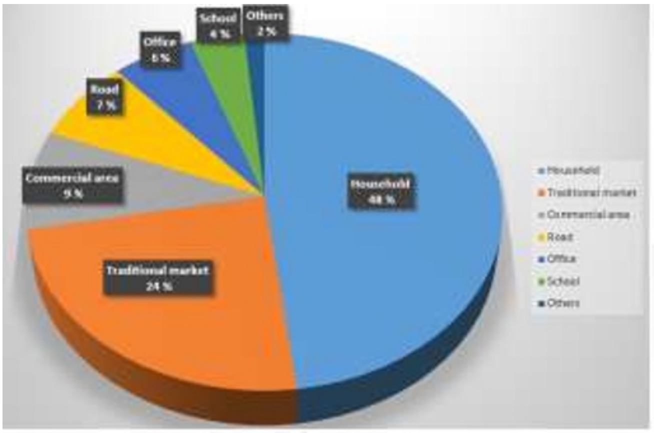

Fig. 1. National waste sources.

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

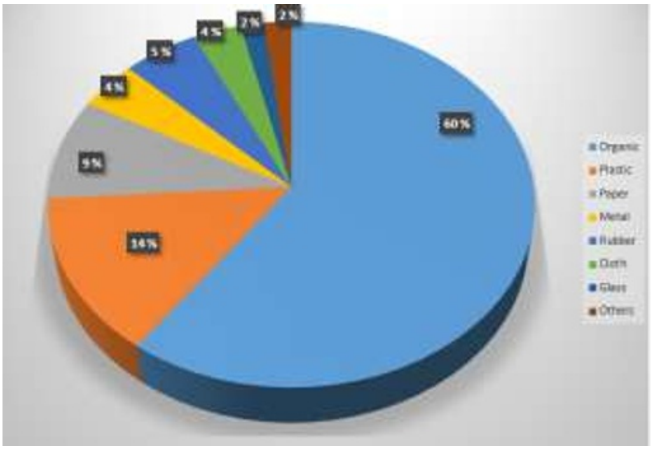

Fig. 2. National waste composition.

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.

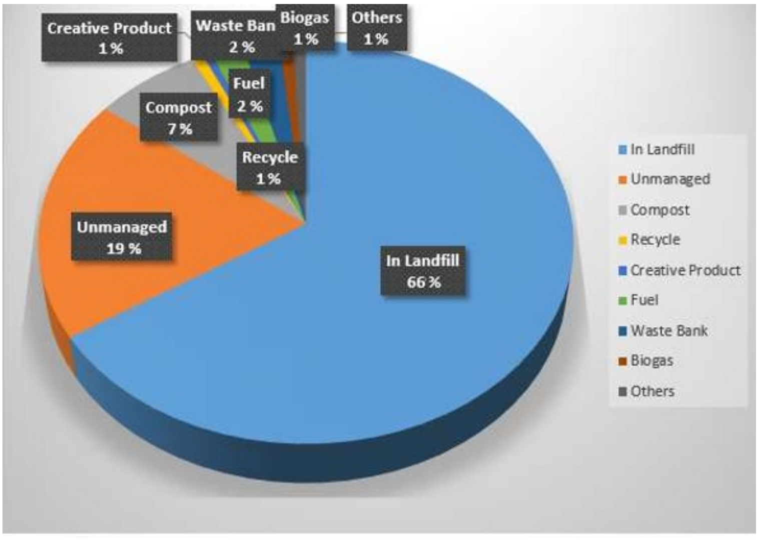

Fig. 3. Percentage of waste processing.

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 3.5×10^6 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 m^3 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 (CH_4) and carbon dioxide (CO_2) [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 CO_2.

Table 1. LFG gas composition.

LFG composition	Chemical formula	Percentage (%)
Methane	CH_4	50 to 70
Carbon dioxide	CO_2	30 to 40
Hidrogen	H_2	5 to 10
Nitrogen	N_2	1 to 2
Dinitrogen oxide	N_2O	0.3
Hidrogen Sulfide	H_2S	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]:

$$L_o = DDOC_M \cdot F \cdot \left(\frac{16}{12}\right) \tag{1}$$

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 *DDOCm*, we need data on the amount of waste contained in a landfill and calculated with the following Equation:

$$DDOC_M = W \cdot DOC \cdot DOC_F \cdot MCF \tag{2}$$

where,
W = total waste (Gg)
DOC = Degradable Organic Carbon
DOCF = 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	6.13×10^7 J
1 kWh	3.6×10^6 J
1 m^3 Methane Gas	4.0213×10^7 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).

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 m^2, and zone 2 is around 35 800 m^2. 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 3.5×10^6 t of waste has been piled up to date. Table 4 shows the average ton of waste received at the landfill each day.

Table 4. Average t d^{-1} at Jatibarang Landfill, Semarang.

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

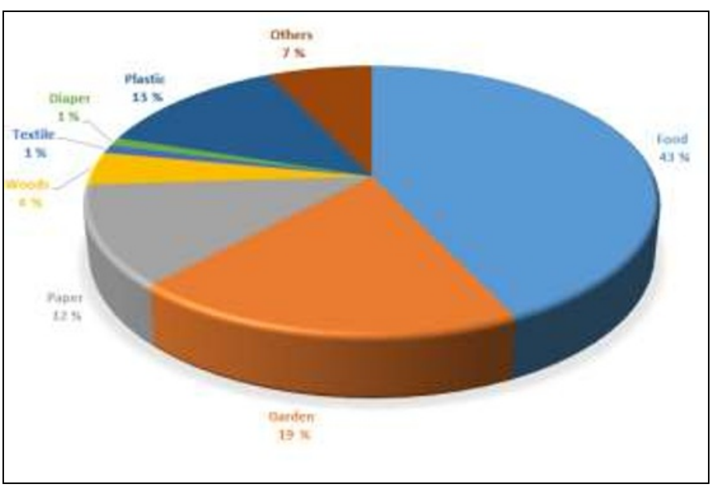

Fig. 5. Waste composition in Jatibarang Landfill, Semarang.

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.

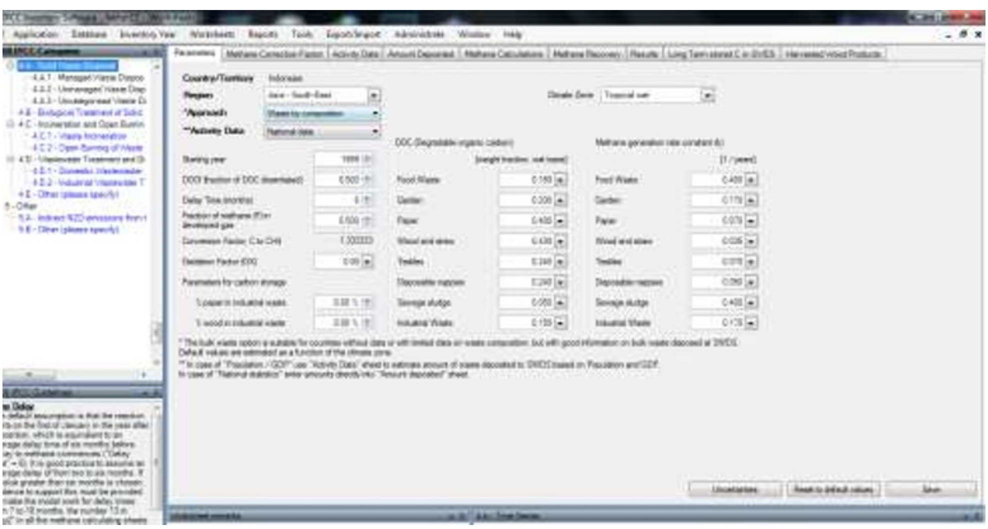

Fig. 6. The initial view of IPCC inventory software.

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 L_O (Equation 1), which will be used as input in LFGCost-WEB software. The value of L_O in LFGCost-WEB software is in (ft^3 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, Jatibarang 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 Jatibarang 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 Jatibarang, 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 Jatibarang operator

Fig. 7. Group of cows in TPA Jatibarang.

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 Jatibarang 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.

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) [assumes 1 well/acre]	22	
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.

Table 7. continued.

Parameter	Set value	Remark
Will LFG energy project cost include collection and flaring costs? (Y)es or (N)o	Y	Based on Scenario
For Direct-use, High Btu, and CHP projects: Distance between landfill and end use,pipeline, or CHP unit (miles)	2 miles	Based on Scenario
For CHP projects: Distance between CHP unit and hot water/steam user (miles)	1 mile	Based on Scenario
Year LFG energy project begins operation	2017	Based on Scenario
LFG energy project size: Gas rate = Minimum, Average, Maximum or Defined by user (must enter design flow rate below)?	Minimum	Based on Scenario
Methane generation rate constant, k (1 yr^{-1})	0.04	Default for typical climate
Potential methane generation capacity of waste, Lo (ft^3 t^{-1})	2 146	Based on IPCC Calculation
Methane content of landfill gas (%)	50	Default value
Average depth of landfill waste (ft)	65	TPA Jatibarang operator
Landfill gas collection efficiency (%)	85	Default value
Utilization of CHP hot water/steam potential (%)	100	Default value
Expected LFG energy project lifetime (yr)	15	Based on Scenario
General inflation rate (% - applied to O&M costs)	2.5	Based on Scenario
Equipment inflation rate (%)	2.0	Based on Scenario
Discount rate (%)	8.0	Based on Scenario
Product price: Electricity generation |(USD kWh^{-1})	USD 0.0600	IndonesianLawfor
Product price: CHP hot water/steam production (USD per 10^6 Btu)	USD 4.00	Default value
Annual product price escalation rate (%)	1.00	Based on Scenario
Annual electricity purchase price escalation rate (%)	0.7	Based on Scenario

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 ft^3 min^{-1} to 3,000 ft^3 min^{-1} LFG
Boiler Retrofit	≤ 3 000 ft^3 min^{-1} LFG
High Btu Processing Plant	1 000 ft^3 min^{-1} to 10 000 ft^3 min^{-1} LFG
Onsite CNG Production and Fueling Station	50 ft^3 min^{-1} to 600 ft^3 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 L_O 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 L_O values in t, then converted to volume units (ft^3) 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 L_O value is in units of ft^3 t^{-1} according to the input requirements in the LFGCostWeb software. The results of calculating the value of L_O 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_O 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).

References

1. E. Damanhuri, W. Handoko, T. Municipal solid waste management in Indonesia. In: *Municipal Solid Waste Management in Asia and the Pacific Islands. Environmental Science and Engineering*. A. Pariatamby, M. Tanaka (Eds). Singapore: Springer (2014). pp. 139–155. https://link.springer.com/chapter/10.1007/978-981-4451-73-4_8
2. Central Bureau of Statistics. *Statistik lingkungan hidup Indonesia* [Environment Statistic of Indonesia] Jakarta: BPS-Statistic Indonesia (2018). p 250. [in Bahasa Indonesia] https://www.bps.go.id/publication/2018/12/07/d8cbb5465bd1d3138c21fc80/statistik-lingkungan-hidup-indonesia-2018.html
3. T. Ahrens, S.D. Hartung, O. Anne. Sustainability of the biomass utilization for energy production. In: Chapter 7, *Biomass volume estimation and valorization for energy*. J.S. Tumuluru (Eds.) Croatia: Intech, (2017). p. 165–185. https://www.intechopen.com/books/biomass-volume-estimation-and-valorization-for-energy/sustainability-of-the-biowaste-utilization-for-energy-production
4. K. Khoiron, A.N. Probandari, W. Setyaningsih, H.S. Kasjono, R.H. Setyobudi, O. Anne. Ann Trop & Public Health S463, **23**,3(A):60–67. http://doi.org/10.36295/ASRO.2020.23316
5. I. Omar, S. Mncwango, J. Eng. Des. Tech., **3**,2:127–139(2005). https://www.emerald.com/insight/content/doi/10.1108/17260530510815367/full/html
6. C.G.I. Partha, Majalah Ilmiah Teknologi Elektro, **9**(2):152–158(2006). [in Bahasa Indonesia]. https://ojs.unud.ac.id/index.php/JTE/article/view/3150
7. S. Ghazi, M. Abbaspour. *Economic evaluation of an industrial biogas system for production of gas, electricity and liquid compost*. Presented in Proceedings of the World Renewable Energy Congress–Sweden (Linköping, Sweden, 2011).

https://www.researchgate.net/publication/269131658_Economic_Evaluation_of_an_Industrial_Biogas_System_for_Production_of_Gas_Electricity_and_Liquid_Compost
8. N.A. Thohiroh, R. Mardiati. *Desain pembangkit listrik tenaga sampah (PLTSa) menggunakan teknologi pembakaran yang fisibel studi kasus TPST Bantargebang*. [The design of the garbage power plant (PLTSa) uses a combustion technology that is feasible in the case study of the Bantargebang TPST]. Presented in SENTER 2017: Seminar Nasional Teknik Elektro (UIN Sunan Gunung Djati, Bandung, Indonesia, 2017). pp. 212–224. [in Bahasa Indonesia]. https://senter.ee.uinsgd.ac.id/repositori/index.php/prosiding/article/view/senter2017p24
9. Z.Z. Noor, R.O. Yusuf, A.H. Abba, M.A.A. Hassan, M.F.M. Din, Renew. Sust. Energ. Rev., **20**:378–384(2013). https://www.sciencedirect.com/science/article/pii/S1364032112006648
10. P.D.P. Dewi, I.W. Suarna, I.W.B. Suyasa, ECOTROPHIC Jurnal Ilmu Lingkungan (Journal Environmental Science), **11**,2:132–139(2017). [in Bahasa Indonesia]. https://ojs.unud.ac.id/index.php/ECOTROPHIC/article/view/32911
11. W.N. Mbav, S. Chowdhury, S.P. Chowdhury, *Feasibility and cost optimization study of landfill gas to energy projects based on a western cape landfill site in South Africa*. Paper Presented in Proceedings of the Universities Power Engineering Conference (London, UK, 2012). http://ieeexplore.ieee.org/document/6398679
12. V.P. Garcilasso, S.M.S.G. Velázquez, S.T. Coelho, L.S. Silva, *Electric energy generation from landfill biogas - Case study and barriers*. Paper Presented in 2011 International Conference on Electrical and Control Engineering, ICECE (Yichang, China, 2011). https://ieeexplore.ieee.org/document/6058122
13. H.-J. Ehrig, H.-J. Schneider, V. Gossow, Waste, 7. Deposition. In: *Ullmann's Encyclopedia of Industrial Chemistry*. Verlag:Wiley (2011). https://onlinelibrary.wiley.com/doi/abs/10.1002/14356007.o28_o07
14. T. Abbasi, S.M. Tauseef, S.A. Abbasi, Renew. Sust. Energ. Rev. **16**,5:3228–3242(2012). https://www.sciencedirect.com/science/article/pii/S1364032112001402
15. Intergovernmental Panel on Climate Change (IPCC). *Climate change 2007: Synthesis report*. Sweden: Teri Press (2008). p. 103. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf
16. W. Purwanta, J. Teknologi Lingkungan, **10**,1:1–8(2016). [in Bahasa Indonesia]. http://ejurnal.bppt.go.id/index.php/JTL/article/view/1497
17. J. Hřebíček, G. Schimak, M. Kubásek, A.E. Rizzoli, *Environmental Software Systems. Fostering Information Sharing*. Verlag Berlin Heidelberg:Springer (2013). p. 699. https://www.springer.com/gp/book/9783642411502
18. Landfill Methane Outreach Program (LMOP). *LFG Energy Project Development Handbook*. United Stated: EPA (2016). p. 139. https://www.epa.gov/sites/production/files/2016-11/documents/pdh_full.pdf
19. S.J. Royer, S. Ferrón, S.T. Wilson, D.M. Karl, PLoS One, **13**,8:1–13(2018). https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0200574