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Waste Management Based On Waste To Energy Technology In Palopo City

Muh. Syainal Nur[1], Achmad Husen[1], Dian Alfia Purwandari[1]
[1]Environmental Management Postgraduate Program, State University of Jakarta, Indonesia
Corresponding Author: Muh. Syainal Nur; Email: msyainalnur@gmail.com

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ABSTRACT

The volume of waste in Indonesia especially in Palopo City increases every year, while the quality of waste management does not show good performance. The large population makes high consumption including energy needs, even though most of the national energy needs come from coal which is a source of pollutants. Waste to energy (WTE) is a modern waste management that utilizes waste into renewable energy, the conversion of waste into energy can be done with landfill gas (LFG) technology and incineration. The study aims to analyze the potential of waste management based on waste-to-energy technology in Palopo City. Quantitative descriptive research with observation and documentation instruments. To calculate the potential energy produced using LandGem-v302 and mathematical equations, to assess the feasibility of economic value using the criteria npv, irr, brc, and pp. The results of this study show that gas landfill technology has the potential to produce renewable energy. The results of the economic feasibility assessment of gas landfill technology meet all four criteria, thus the development of gas landfill technology can provide economic benefits. The results of incineration technology research have the potential to produce renewable energy. But from the results of the economic feasibility assessment unlike gas landfills, the combustion technology does not meet one of the economic value feasibility criteria. So the development of centration technology is not recommended to obtain economic benefits, the development of incineration technology is recommended to reduce waste.

INTRODUCTION

The waste problem is an environmental problem that is still an unsolved polemic because the volume of waste each year tends to increase due to high consumption and population growth (Kneese et al., 2015). This is not accompanied by the success of waste management in landfills, resulting in an imbalance between waste production and waste management. Meanwhile, the success of waste management in reducing waste volume is only 15.88%, 37.11% of waste is managed and 47.02% of waste has not been managed (Rachman et al., 2021). (Nanda & Berruti, 2021) revealed that one of the problems of waste management in landfills, especially with the landfill method, is the limited land to accommodate the volume of waste received, resulting in the accumulation of waste without any action. Waste that is not managed properly can endanger the sustainability of the surrounding environment, such as air pollution due to burning waste, groundwater pollution by waste leachate, and other dangerous diseases (Abubakar et al., 2022).

Another environmental problem is energy, the magnitude of national energy needs mostly relies on energy supplies produced from coal (PLTU). Statistical data shows that at least 60% of our national energy needs come from coal. While we know that energy sources from coal are one of the causes of the climate crisis, air pollution, and other environmental problems, not only that, PLTU also has a negative influence on people's lives in terms of health, social and economic (Lisdiyono, 2023). In addition, coal mining also results in deforestation and climate crisis, high air pollutants (Andrée et al., 2019). There is a need for alternative energy transition to reduce dependence on coal energy and the damage caused by it such as solar, wind, air, and waste energy (Kalair et al., 2021).

As an effort to improve and increase waste management, the government issued Law No. 18

concerning Waste Management. In this law, waste management is not only the application of the 3Rs (reduce, reuse, recycle) but also emphasizes that waste management starts from the time waste is generated until the final management in the landfill. The transformation of waste management continues to develop according to PP No. 79 of 2014 concerning the National Energy Policy waste is categorized into renewable energy sources whose utilization will be directed to electricity and transportation. The transition to waste-based renewable energy can be realized by utilizing WTE technology, one of the advantages of this system is that besides being able to produce energy from waste, it also has economic value benefits (Cudjoe et al., 2021).

Waste to energy (WtE) technology, better known as PLTSa (Pembangkit Listrik Tenaga Sampah) in Indonesia, is modern waste management by utilizing technology to convert waste-based energy, there are two WtE technologies, namely Landfill Gas (LFG) and Incineration technology. LFG technology converts methane gas contained in landfill gas into energy (Bagui & Arellano, 2021; Manasaki et al., 2021), while incineration technology utilizes heat energy from burning waste to be converted into energy (Curry & Pillay, 2011). The main benefits of WtE technology are reducing waste volume, renewable energy sources, and reducing the adverse impact of waste on the environment (Coracero et al., 2021; Muawad & Omara, 2019). In addition, WtE also offers economic and profit potential for the PLTSa business. Waste management with WtE is needed to improve the quality of sustainable waste management, so this needs to be given special attention by the government (Chand Malav et al., 2020).

Across the globe, numerous landfill gas plants have been established to harness landfill gas for energy production. In 2005, approximately 955 landfill gas (LFG) plants existed worldwide, with the United States hosting the majority. This figure has since risen to around 1,000 LFG plants, with a notable shift towards Europe and the United States (Njoku et al., 2018). The technology is gaining prominence in Africa, particularly in South Africa, where 4 operational LFG plants have been spearheaded (Bentil, 2018). In Johannesburg, the Robinson Deep landfill gas recovery initiative commenced in 2016, generating 3 MW of renewable electricity—enough to power over 5,500 homes (Dlamini et al., 2019). Ongoing projects at the Goudkoppies and Marie Louise landfill sites involve gas collection system installation and generator setup, each aiming to produce 3 MW of electricity. Similarly, Ennerdale and Linbro Park landfill sites are anticipated to contribute 1 MW each to the City Power electricity grid (Mbazima et al., 2022). In Malaysia, merely 10% of operational landfill sites follow sanitary practices, and only 5 of them utilize methane recovery for electricity generation (Yong et al., 2019). Contrastingly, Nigeria lacks functional sanitary landfills for energy recovery (Ogunjuyigbe et al., 2017). Several previous studies have also shown the same thing in research conducted at Tamangapa Landfill in Makassar City by utilizing landfill gas technology to produce renewable energy (Yusran et al., 2020). Other research conducted in the city of Medan waste management with incineration technology can produce renewable energy and has economic value (Sihite et al., 2020). Research (Allo & Widjasena, 2019) conducted respectively at the Makbon landfill in Sorong City and the Sambutan landfill in Samarinda City with landfill gas technology show that both can produce renewable energy.

Despite the many benefits of WtE, the policy of development and development of waste management with WtE technology has also received a lot of opposition among academics, communities, and environmental activists (Yuan et al., 2019). This is because there are doubts about optimizing WtE-based management or mismanagement so that it creates other and greater adverse effects on the environment. In addition, the amount of tipping fees that must be paid is a problem in itself.

Palopo City is an area with the status of an intermediate city in South Sulawesi, having its main economic sectors supported by services, tourism, and culinary. This makes Palopo City the largest waste producer in the Luwu Union region which consists of Luwu Regency, Palopo City, North Luwu Regency, and East Luwu Regency. It is known that every day Palopo city produces 60-90 tons of waste.

Table 1. Waste Volume in Palopo City

Year	Ton/Year
2018	16568,6
2019	18792,8
2020	19137,6
2021	18280
2022	17652

Source: Landfill Data

In the implementation of waste management, the Palopo City government has a Regional Technical Implementation Unit (UPTD) Mancani Landfill under the coordination of the Environmental Service. Mancani Landfill has various types of waste management systems such as composting, Waste Bank, and Landfill. However, the limited capacity of landfills and waste management that has not been maximized has resulted in Mancani Landfill over capacity. Therefore, the development of WtE technology will provide benefits to reduce the volume of waste and also produce renewable energy. Renewable energy production with WtE technology independently provides added economic value (Malinauskaite et al., 2017). Based on the description that has been presented previously, researchers are interested in conducting research on the topic of waste to energy in Palopo City with the title "Waste Management Based on Waste to Energy Technology in Palopo City". Based on the background that has been described, the purpose of this research is to analyze the potential for waste management with waste to energy (WtE) technology in the city of Palopo.

MATERIALS AND METHODS

This research is a type of quantitative descriptive research. The instruments used in the research are observation and documentation. The data needed in this research is secondary data.

To obtain the results the researcher used the following research analysis techniques:

1. Waste Volume Projection
   Waste volume projections can be measured by measuring population growth and consumption in an area. In this study, to calculate data projections, researchers used the Geometric method (Xi et al., 2022).
2. LandGEM-v302
   The energy produced from landfill gas technology is obtained from methane gas, to calculate methane gas this research uses an MS-based application. Excel-based application, LandGEM-v302, is an application developed by the United States Environmental Protection Agency (USEPA) (Hecht & Fiksel, 2015).
3. Calculating Electricity Potential with Incineration System
   Incineration technology produces energy from the heat generated from burning waste, so to calculate the energy that can be generated can use mathematical equations. This is done because it is impossible to calculate heat directly at the Mancani landfill because the technology does not yet exist.
4. Calculating the Economic Value of Renewable Energy
   The development of WtE-based renewable energy requires large costs, so it is necessary to conduct an economic feasibility study. The economic feasibility study in this research is limited so that the parameters only include net present value (NPV), internal rate of return (IRR), benefit/cost ratio (B/RC), and payback period (PP) (Newnan et al., 2012).

RESULTS AND DISCUSSION

Palopo City Waste Volume Projection

Palopo City has a population in 2022 of 2022 people, population projections are carried out based on the 2019-2022 population growth rate of 2% / year. While the waste volume rate is considered to be fixed at 0.5 Kg/day/year. Table 2 shows the waste volume projection until 2055.

Table 2. Population and Waste Projection 2023-2055

Year	Population Projection	Waste Projection (tons/Year)
2023	193822	35953,9
2024	197008	36544,9
2025	200246	37145,6
2026	203538	37756,3
2027	206884	38376,9
2028	210284	39007,7
2029	213741	39649
2030	217255	40300,7
2031	220826	40963,2
2032	224456	41636,6
2033	228146	42321

2034	231896	43016,7
2035	235708	43723,8
2036	239582	44442,5
2037	243521	45173,1
2038	247524	45915,6
2039	251593	46670,4
2040	255728	47437,6
2041	259932	48217,4
2042	264205	49010
2043	268548	49815,6
2044	272962	50634,5
2045	277449	51466,8
2046	282010	52312,9
2047	286646	53172,8
2048	291358	54046,9
2049	296147	54935,3
2050	301015	55838,3
2051	305964	56756,2
2052	310993	57689,2
2053	316105	58637,5
2054	321301	59601,4
2055	326583	35953,9

Source: Researcher data processing, 2024

The data shown in the table is projected data on the population and amount of waste generation in Palopo 2023-2055. The population projection data obtained has the same average rate value as the population data for the city of Palopo for the 2016-2022 period, namely 2%, so the projection data can be used. Meanwhile, the projected data on the amount of waste generation was obtained by calculating the accumulated data on the projected population for 2023-2044 and the estimated waste generation per person/day (0.5 Kg/day). Projection data shows that there is an increase in the amount of waste generated every year in proportion to population growth of 2%. The only influencing factor in the waste volume projection data obtained is the population.

Waste-based Renewable Energy Potential of Landfill Gas Technology

Landfill gas technology converts waste into energy by utilizing methane gas produced by microorganism processes. The amount of methane gas is calculated using the LandGEM-v302 application, and the energy production from the conversion of methane gas to energy is calculated using the principle that 1 m3 of methane gas is worth 11.17 kWh (Galavote et al., 2022).

In this study, it was determined that the waste acceptance capacity of the landfill at the Mancani landfill in Palopo City was 269,064 tons. Thus it is known that the Mancani landfill will reach the capacity limit in 2030. Meanwhile, to crunch the sales value of landfill-based energy with medium voltage is Rp.2,491/kWh (Permen ESDM No. 44 Tahun 2015).

Table 3. Landfill Gas Renewable Energy Potential

Year	Waste received (tons)	Waste Produced (tons)	Methane gas (m3/Year)	Energy (kWh)	Sales (Rp)
2024	35.954	0,00	0,00	-	-
2025	36.545	35.953,89	271.672,28	3.034.579,34	7.559.137.142
2026	37.145,64	72.498,80	534.560,75	5.971.043,57	14.873.869.526
2027	37.756,25	109.644,45	789.167,22	8.814.997,79	21.958.159.505
2028	38.376,90	147.400,70	1.035.970,21	11.571.787,26	28.825.322.055
2029	39.007,75	185.777,60	1.275.426,16	14.246.510,20	35.488.056.902
2030	39.648,96	224.785,34	1.507.970,47	16.844.030,14	41.958.479.089
2031		264.434,31	1.734.018,58	19.368.987,58	48.248.148.060
2032		264.434,31	1.649.449,50	18.424.350,91	45.895.058.113
2033		264.434,31	1.569.004,90	17.525.784,71	43.656.729.716
2034		264.434,31	1.492.483,63	16.671.042,10	41.527.565.883
2035		264.434,31	1.419.694,34	15.857.985,79	39.502.242.596
2036		264.434,31	1.350.455,03	15.084.582,69	37.575.695.491

2037	264.434,31	1.284.592,56	14.348.898,91	35.743.107.197
2038	264.434,31	1.221.942,24	13.649.094,86	33.999.895.289
2039	264.434,31	1.162.347,42	12.983.420,65	32.341.700.829
2040	264.434,31	1.105.659,06	12.350.211,75	30.764.377.467
2041	264.434,31	1.051.735,44	11.747.884,81	29.263.981.073
2042	264.434,31	1.000.441,69	11.174.933,71	27.836.759.875
2043	264.434,31	951.649,58	10.629.925,76	26.479.145.075
2044	264.434,31	905.237,08	10.111.498,17	25.187.741.931
2045	264.434,31	861.088,15	9.618.354,58	23.959.321.262
2046	264.434,31	819.092,38	9.149.261,89	22.790.811.375
2047	264.434,31	779.144,77	8.703.047,13	21.679.290.388
2048	264.434,31	741.145,43	8.278.594,51	20.621.978.920
2049	264.434,31	704.999,35	7.874.842,69	19.616.233.140
2050	264.434,31	670.616,12	7.490.782,08	18.659.538.161
2051	264.434,31	637.909,79	7.125.452,33	17.749.501.746
2052	264.434,31	606.798,56	6.777.939,92	16.883.848.331
2053	264.434,31	577.204,65	6.447.375,89	16.060.413.331
2054	264.434,31	549.054,04	6.132.933,65	15.277.137.730
2055	264.434,31	522.276,36	5.833.826,95	14.532.062.931
2056	264.434,31	496.804,64	5.549.307,85	13.823.325.859
2057	264.434,31	472.575,19	5.278.664,91	13.149.154.301
2058	264.434,31	449.527,43	5.021.221,39	12.507.862.479
2059	264.434,31	427.603,72	4.776.333,53	11.897.846.827
2060	264.434,31	406.749,24	4.543.389,00	11.317.581.990
2061	264.434,31	386.911,84	4.321.805,30	10.765.617.004
2062	264.434,31	368.041,93	4.111.028,37	10.240.571.667
2063	264.434,31	350.092,31	3.910.531,15	9.741.133.093
2064	264.434,31	333.018,11	3.719.812,29	9.266.052.426
2065	264.434,31	316.776,63	3.538.394,91	8.814.141.717
2066	264.434,31	301.327,25	3.365.825,35	8.384.270.953
2067	264.434,31	286.631,34	3.201.672,11	7.975.365.233
2068	264.434,31	272.652,17	3.045.524,72	7.586.402.081
2069	264.434,31	259.354,77	2.896.992,73	7.216.408.885
2070	264.434,31	246.705,88	2.755.704,73	6.864.460.471
2071	264.434,31	234.673,90	2.621.307,42	6.529.676.783
2072	264.434,31	223.228,72	2.493.464,75	6.211.220.689
2073	264.434,31	212.341,72	2.371.857,04	5.908.295.881
2074	264.434,31	201.985,69	2.256.180,21	5.620.144.891
2075	264.434,31	192.134,74	2.146.145,00	5.346.047.190
2076	264.434,31	182.764,21	2.041.476,27	5.085.317.392
2077	264.434,31	173.850,70	1.941.912,30	4.837.303.536
2078	264.434,31	165.371,90	1.847.204,12	4.601.385.459
2079	264.434,31	157.306,62	1.757.114,91	4.376.973.242

2080	264.434,31	149.634,68	1.671.419,41	4.163.505.738
2081	264.434,31	142.336,91	1.589.903,32	3.960.449.167
2082	264.434,31	135.395,06	1.512.362,82	3.767.295.782
2083	264.434,31	128.791,76	1.438.604,01	3.583.562.599
2084	264.434,31	122.510,52	1.368.442,47	3.408.790.188
2085	264.434,31	116.535,61	1.301.702,74	3.242.541.529
2086	264.434,31	110.852,10	1.238.217,95	3.084.400.913
2087	264.434,31	105.445,78	1.177.829,35	2.933.972.905
2088	264.434,31	100.303,13	1.120.385,93	2.790.881.358
2089	264.434,31	95.411,29	1.065.744,07	2.654.768.468
2090	264.434,31	90.758,02	1.013.767,11	2.525.293.882
2091	264.434,31	86.331,70	964.325,11	2.402.133.846
2092	264.434,31	82.121,25	917.294,42	2.284.980.396
2093	264.434,31	78.116,15	872.557,44	2.173.540.587
2094	264.434,31	74.306,38	830.002,31	2.067.535.762
2095	264.434,31	70.682,42	789.522,62	1.966.700.853
2096	264.434,31	67.235,20	751.017,15	1.870.783.720
2097	264.434,31	63.956,10	714.389,61	1.779.544.522
2098	264.434,31	60.836,92	679.548,42	1.692.755.111
2099	264.434,31	57.869,87	646.406,45	1.610.198.470
2100	264.434,31	55.047,52	614.880,84	1.531.668.164
2101	264.434,31	52.362,82	584.892,74	1.456.967.826
2102	264.434,31	49.809,06	556.367,19	1.385.910.667
2103	264.434,31	47.379,84	529.232,84	1.318.319.006
2104	264.434,31	45.069,10	503.421,85	1.254.023.830
2105	264.434,31	42.871,05	478.869,68	1.192.864.366
2106	264.434,31	40.780,21	455.514,93	1.134.687.684
2107	264.434,31	38.791,33	433.299,20	1.079.348.313
2108	264.434,31	36.899,46	412.166,95	1.026.707.874
2109	264.434,31	35.099,85	392.065,33	976.634.740
2110	264.434,31	33.388,01	372.944,08	929.003.702

Source: Researcher data processing, 2024

Waste-based renewable energy is produced by methane gas produced from waste generated in landfills, every 1 m3 of methane gas is equivalent to 11.17 kWh. Meanwhile, for revenues from the sale of renewable energy, it is assumed that all the energy produced will be sold. Referring to Minister of Energy and Mineral Resources Regulation No. 44 of 2015 concerning the purchase of electricity by PLN from municipal waste-based power plants, the purchase of electrical energy for landfills with medium voltage is IDR 2,491/kWh.

USEPA, (2007) explains that the investment cost of landfill gas technology includes direct and indirect costs. The cost required for landfill gas technology with a waste acceptance capacity of 100 tons/day is USD 10,594,350 or equivalent to IDR 148,320,900,000.

The assessment of the economic feasibility of renewable energy based on landfill gas system waste is carried out by calculating the investment criteria, namely NPV, IRR, BCR, PP which are calculated using MS tools. excel. The results of calculations and evaluations of the economic feasibility of renewable energy potential based on waste from the Mancani Palopo TPA landfill gas system can be seen in the following table:

Table 4. Feasibility Assessment of the Economic Value of Landfill Gas Technology

Criteria	Value	Eligibility	Result
NPV	Rp135,813,108,537	NPV > 0	Met
IRR	19%	IRR > 10%	Met
BRC	1.92	BRC > 1	Met
PP	8.09 Year	PP < 32 Year	Met

Source: Researcher data processing, 2024

The results of the economic value feasibility test show that renewable energy produced from methane gas can be categorized as feasible because it meets four criteria, namely NVP, IRR, BRC, PP. Thus, the results of waste to energy technology by utilizing landfill gas to produce renewable energy are promising from an economic perspective.

Waste acceptance in landfills starts from 2024 to 2030 with a total of 264,434.31 tons of waste in landfills. From the LandGEM-v302 calculation, it is known that methane gas was successfully produced from 2025 to 2110, the amount of methane gas produced fluctuates as in Table 3. Methane gas produced in landfills is the main raw material for energy production, so the amount of energy produced depends on the amount of methane gas obtained from landfills (Purmessur & Surroop, 2019). From the assessment of economic feasibility using four criteria for landfill gas technology, we can categorize it as feasible. So the development and construction of PLTSa with landfill gas technology is very possible. In addition to improving the quality of waste management, it can also benefit economically.

Fei et al., (2019) explained that big cities in China began to implement policies to reduce waste in landfills to zero. To realize this, they carry out waste management using landfill gas technology. By meeting sanitary landfill management standards and increasing human resources in landfills will help maximize the performance of landfill gas technology. In addition to reducing waste, landfill gas technology also helps reduce CO2 emissions and produce energy. Another study conducted at the Mare Chicose landfill concluded that the future contribution of landfill technology will increase to 20% (Purmessur & Surroop, 2019).

Waste-based Renewable Energy Potential Incineration Technology

Incineration technology utilizes heat energy from burning waste, heat energy is converted into energy through boilers. In accordance with Palopo City's waste projection data, it is assumed that the Mancani Landfill uses incineration technology with a combustion capacity of 100 tons/day. This needs to be considered so that the costs incurred both investment and maintenance can be minimized. Ministerial Regulation No. 44 of 2015 regulates the amount of selling value of energy derived from incineration with medium voltage, which is Rp. 2,825/kWh.

This research assumes that the incineration technology used at the Mancani Palopo TPA is incineration technology which has a waste management capacity of 100 tons/day. So the waste data for the incineration system is obtained as follows:

Table 5. Waste-based Renewable Energy Potential of Incineration Technology

Year	Waste Volume (tons/year)	Waste Processed (tons/year)	Remaining (tons)	Calorific Energy (Kj)	Renewable Energy (kWh)	Sales Value (Rp)
2024	35.953,89	35.953,89	0,00	141.910,05	310.783,00	877.961.982
2025	36.544,91	36.500,00	44,91	144.065,53	315.503,51	891.297.424
2026	37.145,64	36.500,00	645,64	144.065,53	315.503,51	891.297.424
2027	37.756,25	36.500,00	1.256,25	144.065,53	315.503,51	891.297.424
2028	38.376,90	36.500,00	1.876,90	144.065,53	315.503,51	891.297.424
2029	39.007,75	36.500,00	2.507,75	144.065,53	315.503,51	891.297.424

2030	39.648,96	36.500,00	3.148,96	144.065,53	315.503,51	891.297.424
2031	40.300,72	36.500,00	3.800,72	144.065,53	315.503,51	891.297.424
2032	40.963,19	36.500,00	4.463,19	144.065,53	315.503,51	891.297.424
2033	41.636,55	36.500,00	5.136,55	144.065,53	315.503,51	891.297.424
2034	42.320,98	36.500,00	5.820,98	144.065,53	315.503,51	891.297.424
2035	43.016,67	36.500,00	6.516,67	144.065,53	315.503,51	891.297.424
2036	43.723,78	36.500,00	7.223,78	144.065,53	315.503,51	891.297.424
2037	44.442,52	36.500,00	7.942,52	144.065,53	315.503,51	891.297.424
2038	45.173,08	36.500,00	8.673,08	144.065,53	315.503,51	891.297.424
2039	45.915,64	36.500,00	9.415,64	144.065,53	315.503,51	891.297.424
2040	46.670,42	36.500,00	10.170,42	144.065,53	315.503,51	891.297.424
2041	47.437,59	36.500,00	10.937,59	144.065,53	315.503,51	891.297.424
2042	48.217,38	36.500,00	11.717,38	144.065,53	315.503,51	891.297.424
2043	49.009,99	36.500,00	12.509,99	144.065,53	315.503,51	891.297.424
2044	49.815,63	36.500,00	13.315,63	144.065,53	315.503,51	891.297.424
2045	50.634,51	36.500,00	14.134,51	144.065,53	315.503,51	891.297.424
2046	51.466,85	36.500,00	14.966,85	144.065,53	315.503,51	891.297.424
2047	52.312,87	36.500,00	15.812,87	144.065,53	315.503,51	891.297.424
2048	53.172,80	36.500,00	16.672,80	144.065,53	315.503,51	891.297.424
2049	54.046,87	36.500,00	17.546,87	144.065,53	315.503,51	891.297.424
2050	54.935,30	36.500,00	18.435,30	144.065,53	315.503,51	891.297.424
2051	55.838,34	36.500,00	19.338,34	144.065,53	315.503,51	891.297.424
2052	56.756,22	36.500,00	20.256,22	144.065,53	315.503,51	891.297.424
2053	57.689,19	36.500,00	21.189,19	144.065,53	315.503,51	891.297.424
2054	58.637,50	36.500,00	22.137,50	144.065,53	315.503,51	891.297.424
2055	59.601,40	36.500,00	23.101,40	144.065,53	315.503,51	891.297.424

Source: Researcher data processing, 2024

With incinerator technology with a capacity of 100 tons/day, it is also intended to produce waste-based renewable energy. Incinerators are also able to directly reduce waste which will help extend the life of the controlled landfill. Previously it was known that the capacity of the control landfill was 269,064 tons, if it was operated in 2024 it would only be able to accept waste until 2030. However, with the implementation of incineration technology with a capacity of 100 tons/day and starting to operate in the same year, namely 2024, the controlled landfill would be capable of operating until 2052 as in the table.

Incineration technology is a technology that uses heat to produce steam to drive turbines to produce renewable energy. To calculate the potential for renewable energy that can be produced from the data in Table 5, use several equations that have been described previously. Meanwhile, sales receipts assume that all the renewable energy power produced will be sold. Referring to Ministerial Regulation no. 44 of 2015 concerning the purchase of electricity by PLN from municipal waste-based power plants, the purchase of electrical energy for Incineration/Thermal with medium voltage is IDR 2,825/kWh.

From data that can be seen since 2024, the start of production of incineration technology has produced energy that has been successfully converted from waste generation. In contrast to landfill technology which requires a certain time scale to produce energy, the second difference is that the energy production produced by incineration has a fixed value and tends to be constant according to its burning capacity unless the waste is reduced. Meanwhile, energy production from landfill technology increases until the peak year of production and decreases if it has passed the peak year of production. However, both technologies are equally capable of producing renewable energy from waste generated in landfills.

USEPA, (2007) explains that the investment cost of incineration technology includes direct and indirect costs. The cost required for incineration technology with a waste-burning capacity of 100 tons/day is USD 5,630,660 or equivalent to IDR 78,829,240,000. Assessment of the feasibility of the economic value of an investment can be done based on four criteria, namely npv, irr, bcr and pp. The assessment results can be seen in Table 6 below:

Table 6. Assessment of the Feasibility of Economic Value of Incineration Technology

Criteria	Value	Eligibility	Result
NPV	-Rp69,502,658,017	NPV > 0	Unmet
IRR	-6%	IRR > 10%	Unmet
BRC	0.11	BRC > 1	Unmet
PP	5,971 Year	PP < 32 Year	Unmet

Source: Researcher data processing, 2024

Incineration technology obtains heat energy from burning waste. The combustion capacity of the incineration technology is 100 tons/day capable of producing heat energy of 144,065.53 kJ and can be converted into electricity of 315,503.51 kWh every year from 2025 to 2055, in 2024 the burning of waste does not reach the capacity limit so that the energy generated in 2024 is not optimal. In contrast to landfill gas technology, incineration technology consistently produces energy provided that the waste processed reaches 100 tons/day. Although the regeneration technology produces energy and obtains sales value from the energy, from the results of the economic feasibility assessment the regeneration technology does not meet one of the four criteria that have been determined so that it can be categorized as not economically feasible. However, from the aspect of waste reduction, incineration technology is more effective than landfill gas technology.

Gu et al., (2021) explained the use of incineration technology in Beijing City due to its ability to produce energy and reduce waste faster. In Mexico, the energy produced by incineration technology can contribute and account for 4.3% of national needs (Escamilla-García et al., 2020). Incineration waste reduction is faster than landfill gas because the process is through burning waste in a container, unlike landfill gas which requires a chemical process with the help of microorganisms (Kaur et al., 2021).

The implementation of waste-to-energy has demonstrated a positive impact on mitigating global warming by reducing greenhouse gas emissions, particularly carbon dioxide (CO_2) when compared to the baseline scenario of waste dumping, open burning, and landfill with the gas collection. Regarding climate change mitigation, incinerating one tonne of municipal solid waste (MSW) in a thermal waste-to-energy (WtE) plant can result in avoiding approximately 1,010 kg of CO_2, excluding biogenic carbon emissions, by diverting waste from landfills without methane gas utilization (United Nations Environment Programme (UNEP), 2019). Furthermore, the CO_2 emissions from an incinerator stand at 0.22 kg CO_2/kWh, while a gasification plant emits lower CO_2, approximately 0.114 kg CO_2/kWh. Estimates for CO_2 emissions from electricity generated through anaerobic digestion (AD) plants are around 0.2 kg CO_2/kWh, whereas landfill gas recovery systems emit 1–1.2 kg CO_2/kWh (Moore & Zhang, 2020). Among various waste-to-energy technologies, anaerobic digestion has been identified as the most environmentally friendly, as supported by research (O. E. Alao & Onah, 2020). Specifically, a study by (Khan & Kabir, 2020) revealed that gasification, pyrolysis, and anaerobic digestion were 33%, 65%, and 111% more sustainable for waste-to-energy generation compared to direct combustion.

While developed nations have successfully embraced waste-to-energy (WtE) technologies, their implementation faces challenges in developing countries. These challenges span logistical, technical, financial, socio-environmental, and policy-related aspects. In terms of logistics, insufficient waste collection infrastructure and a lack of waste segregation at the source pose significant obstacles to waste-to-energy implementation in developing countries. Technical challenges include the limited availability of data on waste quality and quantity, crucial for determining the waste's calorific value through physical and chemical analyses. Insufficient knowledge about waste composition may lead to inappropriate equipment and technology choices, wasting resources and time (Ehtasham, 2022; Oelofse et al., 2016).

From an economic perspective, WtE technologies are capital-intensive, requiring costly equipment (Aleluia & Ferrão, 2017). Many developing nations lack the financial capacity to invest in waste-to-energy, as construction, start-up, operation, and maintenance costs of incineration facilities may be prohibitively high (Bishoge et al., 2019). For instance, in Malaysia, incinerator operations were halted due to the high operational costs associated with fuel and maintenance (Shafie & Rizal, 2019). To enhance cost-effectiveness, governments should establish financial incentives such as Feed-in-Tariff, Carbon Reduction Credits, Tax exemptions, and Renewable Energy Credits to encourage investments in the waste-to-energy sector (Sakah et al., 2017).

The regulatory framework and policies need legislative action to stimulate public-private partnerships in the waste-to-energy market (Cui et al., 2020). Feedstock availability is pivotal, necessitating strict sanctions and penalties on waste landfilling (Bauer et al., 2022). Implementing standard gate or tipping fees, as seen in developed countries, can maximize waste diversion from landfills, ensuring sufficient waste feedstock for waste-to-energy implementation (M. A. Alao et al., 2022). Segregation of waste improves calorific value and reduces operating costs compared to mixed waste types (Kumar & Samadder, 2017). Source separation, enforced through laws and regulations, is crucial, as it not only enhances waste situations at the community level, particularly in African municipalities (Stafford, 2019), but also ensures cost-effectiveness in waste-to-energy implementation through law enforcement compliance.

CONCLUSION

After obtaining the results of testing the potential of waste-based renewable energy with landfill gas and incineration technology in Palopo City using projected waste volume data. The researcher concluded (a) Landfill gas technology with a waste capacity of 269,064 tons has the potential to produce renewable energy starting from 2025 to 2110 and is feasible from an economic perspective after meeting the four criteria of NPV, IRR, BRC, and PP. Thus it can be concluded that landfill gas technology is useful to produce renewable energy and obtain economic value. (b) Incineration technology with a combustion capability of 100 tons/day can produce renewable energy consistently at 144,065.53 kWh from 2024 to 2055. However, from an economic point of view, the incineration technology does not meet the criteria for economic viability that have been determined so it is categorized as not feasible. However, in terms of waste reduction, regeneration technology is better. Thus it can be concluded that regeneration technology can produce renewable energy and is very good for reducing waste.

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