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Techno-Economic Feasibility Analysis of Waste-to-Energy Power Plant Based on Anaerobic Digestion: A Case Study on Sabira Island

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Abstract—*This study explores the techno-economic feasibility of establishing a small-scale waste-to-energy (WTE) power plant using anaerobic digestion technology on Sabira Island, one of the outermost islands of Jakarta, Indonesia. As an isolated area with limited energy access and increasing organic waste generation—estimated at around 1 to 1.2 tons per day—Sabira presents both an environmental challenge and a renewable energy opportunity. Through the conversion of organic waste into biogas, which can then be used to generate electricity, this project seeks to address waste management issues while contributing to sustainable energy production in remote regions. A comprehensive techno-economic analysis was conducted, incorporating factors such as capital and operational costs, biogas yield potential, energy conversion efficiency, and local electricity pricing. Two different electricity selling price scenarios were evaluated to determine financial viability. The results show that under the first pricing scheme, the project fails to meet the minimum return expectations, whereas the second scenario demonstrates acceptable economic performance, suggesting that the project can be considered feasible if more favorable electricity tariffs are adopted. The study concludes that successful implementation of such a WTE system would depend not only on technical and economic parameters but also on supportive policy frameworks, appropriate pricing mechanisms, and access to clean energy financing. The findings offer valuable insights for policymakers and stakeholders aiming to promote decentralized renewable energy solutions in Indonesia's remote islands.*

Keywords : *Waste for Energy, Electrical, Anaerobic Digestion, Renewable Energy*

I. INTRODUCTION

Indonesia, as one of the world's largest archipelagic nations, faces a unique set of challenges in providing reliable electricity and sustainable waste management solutions to its outer and remote islands. Sabira Island, located at the northernmost part of Jakarta's Thousand Islands Regency, is a small but inhabited island that exemplifies these dual issues. Due to limited access to centralized waste processing and electricity infrastructure, the local community relies heavily on diesel generators (PLTD) for power and often resorts to open burning for waste disposal. These practices not only burden the environment but also pose health and sustainability risks.

In recent years, the Indonesian government has promoted the development of renewable energy sources such as solar photovoltaic systems (PLTS). However, on islands like Sabira, PLTS alone is often insufficient due to intermittent generation and limited energy storage capacity, especially during cloudy or rainy seasons. Moreover, the increasing electricity demand continues to outpace the supply capabilities of existing systems. As such, there is a critical need for complementary and more resilient energy sources that can operate independently of weather conditions.

At the same time, the substantial proportion of organic waste generated daily on Sabira Island estimated between 1 to 1.2 tons per day presents an untapped opportunity for local energy generation. Waste-to-energy (WtE) technologies, particularly anaerobic digestion (AD),[6] offer a viable pathway to address both energy and environmental challenges in one integrated solution. Anaerobic digestion is a biological process that converts organic waste into biogas, primarily methane, which can be used as a fuel for electricity generation.

This study explores the feasibility of implementing a small-scale WtE power plant based on anaerobic digestion technology in Sabira Island. The research focuses on evaluating the technical potential of local organic waste as a feedstock and analyzing the economic viability of the project under two electricity pricing scenarios. The goal is to determine whether PLTSa-AD can serve as a sustainable and replicable model for remote island communities across Indonesia.

The anaerobic digestion process occurs in several biological phases hydrolysis, acidogenesis, acetogenesis, and methanogenesis culminating in the production of methane-rich biogas. The key parameter that determines biogas yield is the amount of Volatile Solid (VS) content within the Total Solid (TS) fraction of organic waste.

- **Total Solid (TS)** refers to the dry matter in the organic waste (in % of feedstock weight).
- **Volatile Solid (VS)** is the combustible portion of TS, and directly contributes to methane production.

According to Frear et al. (Washington State University, 2005)[1], the estimation of biogas and methane production from organic waste in an anaerobic digester can be modeled through the following formulas:

Table 1 TS and VS Calculation

types of waste (Kg)	TS (%)	VS (%)	Biogas Productionn (M^3/Kg TS)	Reference
Organic waste	27,7	74,1	0,676	Tanya McDonald, Gopal Achari and Abimbola Abiola on Article Feasibility of increased biogas production from the co-digestion of agricultural, municipal and agro-industrial wastes in rural communities[2]

To calculate the amount of potential electrical energy produced in an anaerobic digestion process, the amount of methane gas is a parameter that is directly related to the amount of electrical energy, while other gases are not related to the process, the amount of methane produced based on the amount of volatile solid (VS) for 1 kg of organic waste mixture is as in the following table (K.Muthupandi, March 2007).

Table 2. Biogas Calculation

Biogass Production (m^3 / hari)	Total Gas Metane (%)	Reference
VBS	60	K.Muthupandi, March 2007)[3]

Engineering Economics is a process related to methods that allow someone to make economic decisions to minimize costs and or maximize benefits for business organizations on technical problems (Panneerselvam, 2012). In order for the target of engineering economics to be achieved, the solution provided must show a positive benefit to long-term costs. In addition, the solution provided must also show the sustainability of an organization from the idea to the expected technology.

Economic analysis in planning the construction of PLTSa with Anaerobic Digestion technology is very important, because it is closely related to the economic feasibility of the project.

1. Life Cycle Cost

Life Cycle Cost(LCC) is an approach in economic analysis that calculates the total costs that will arise during the life of a project.[4]

$$LCC = EC + IC + SV + NFOMC + NRC + RC \quad (1)$$

Where:

LCC:present valuefrom LCC value

E.C.: present valuefrom energy costs

IC : present valuefrom investment costs

SV : present valuefrom the value of the asset after use (salvage)

NFOMC: present value of operating costs and repair costs that recur each year

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NRC: present valuefrom operational costs and repair costs that do not recur every year

RC : present valuefrom other costs

2. Cost of Energy

Cost of energy (COE) is a comparison between the total cost per year of the system with the energy produced during the same period.[5]

$$COE = \frac{LCC\ X\ CRF}{Total\ Energi\ yang\ dihasilkan\ (kWh)} \quad (2)$$

Where:

COE: Cost of Energy

LCC:Life Cycle Cost value or life cycle cost

CRF: Cost Recovery Factor

3. Levelized Cost of Energy

Levelized Cost of energy (LCOE) is used to assess how much it costs a system to produce power per unit of time.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + O_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (3)$$

Where:

I_t : investment cost in year t
O_t : operating cost in year t
M_t : maintenance cost in year t
F_t : fuel cost (if any) in year t
E_t : energy produced (kWh) in year t
r : discount rate (interest rate)
n : project life (in years)

4. Internal Rate of Return

Internal Rate of Return (IRR) is a financial measure that shows the rate of return of an investment project. IRR is calculated based on cash inflows and outflows that occur during the life of the project and is technically defined as the discount rate at which the net value of the cash flows becomes zero.

$$IRR = i_1 + \left[\frac{NPV_1}{NPV_1 - NPV_2}(i_2 - i_1)\right] \quad (4)$$

Where :

i1 : interest value that produces a positive NPV value

i2 : interest value that produces negative NPV

NPV1 : positive NPV value

NPV2 : negative NPV value

5. Net Present Value

NPV is a parameter that uses a relevant interest rate to calculate the difference between the present value of total investment and the present value of total revenue during the operational period.

$$\text{NPV} = \sum_{t=o}^{n} \frac{B_n = C_n}{(1+i)^n} \quad (5)$$

Where :

Bn :receipts in year n
Cn : totalinvestment costs in year n
n : timeoperating system (year)
i :interest rate per year (%)

II. RESEARCH METHODS

The study uses field surveys to estimate daily waste volume and composition. Techno-economic modeling includes: Total Solid (TS) and Volatile Solid (VS) content biogas yield, and methane output. The economic analysis applies two tariff scenarios over a 25-year project life using NPV, IRR, and DPP metrics. The system design assumes integration with existing PLTS and PLTD infrastructure on Sabira Island.

III. RESULT AND ANALYSIS

Based on waste generation data, Sabira Island produces approximately 1 to 1.2 tons of waste per day, with organic waste dominating the composition at 83.35%, and the remaining 16.65 % consisting of non-organic materials and other residues.

Table 3. Presentage of Waste Amount

Type of waste	Presentage (%)
Organic	83,35%
Non-Organic	16,65%

From this volume, the average daily Total Solid (TS) content is estimated at 336.58 kg, with Volatile Solid (VS) content reaching 249.4 kg per day. These VS materials can be converted into biogas with an estimated volume of 168.6 kg/day, which in turn contains approximately 101.16 kg/day of methane gas (CH_4). The energy potential of this methane is equivalent to approximately 0.9944 MWh/day of electricity.

Table 4. Energy Calculation

No	Daily Garbage Pile	TS (27,7%* Total Garbage Pile) kg/day	VS (74,1%* TS), kg/day	VBS (67,6%*VS), kg/day	VGM (60%*VBS) kg/day	E (VGM*9,39/1x10^3), MWh
1	1222	338,494	250,8241	169,5571	101,7342	0,94918
2	1229	340,433	252,2609	170,5283	102,317	0,954618
3	1204	333,508	247,1294	167,0595	100,2357	0,935199
4	1178	326,306	241,7927	163,4519	98,07114	0,915004
5	1277	353,729	262,1132	177,1885	106,3131	0,991901
6	1121	310,517	230,0931	155,5429	93,32576	0,870729
7	1316	364,532	270,1182	182,5999	109,5599	1,022194
8	1275	353,175	261,7027	176,911	106,1466	0,990348
9	1109	307,193	227,63	153,8779	92,32673	0,861408
10	1264	350,128	259,4448	175,3847	105,2308	0,981804
11	1164	322,428	238,9191	161,5093	96,90561	0,904129
12	1123	311,071	230,5036	155,8204	93,49226	0,872283
13	1746	483,642	358,3787	242,264	145,3584	1,356194
14	1232	341,264	252,8766	170,9446	102,5668	0,956948
15	1538	426,026	315,6853	213,4032	128,0419	1,194631
16	1241	343,757	254,7239	172,1934	103,316	0,963939
17	843	233,511	173,0317	116,9694	70,18164	0,654795
18	1477	409,129	303,1646	204,9393	122,9636	1,14725
19	1158	320,766	237,6876	160,6768	96,40609	0,899469
20	1346	372,842	276,2759	186,7625	112,0575	1,045497
21	1351	374,227	277,3022	187,4563	112,4738	1,04938
22	1147	317,719	235,4298	159,1505	95,49032	0,890925
23	1504	416,608	308,7065	208,6856	125,2114	1,168222
24	1226	339,602	251,6451	170,1121	102,0672	0,952287
25	1358	376,166	278,739	188,4276	113,0565	1,054818
26	1221	338,217	250,6188	169,4183	101,651	0,948404
27	1347	373,119	276,4812	186,9013	112,1408	1,046273
28	1173	324,921	240,7665	162,7581	97,65488	0,91112
29	1487	411,899	305,2172	206,3268	123,7961	1,155017
30	1608	445,416	330,0533	223,116	133,8696	1,249003
31	1224	339,048	251,2346	169,8346	101,9007	0,950734
total	39709	10999,39	8150,55	5509,772	3305,863	30,8437
					average/day (MW)	0,994958
					total energy 1 year (MW)	363,1597

Based on the table above, it can be concluded that in one day it produces an average of 0.9944 MW of electrical energy. In one year, the electrical energy that can be produced is 363.15 MW

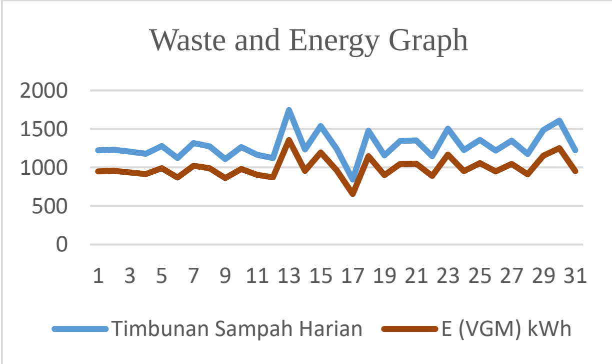

Figure 1. Waste and Energy Graph

Referring to Article 5 of Presidential Regulation of the Republic of Indonesia Number 112 of 2022(Presidential Regulation of the Republic of Indonesia Number 112 of 2022, 2022), it is stated that the purchase price of electricity from power plants that utilize renewable energy sources is listed in the table below, taking into account the location factor (F). The purchase price of electricity from Waste Power Plants (PLTSa) with land provided by the government (excluding battery facilities or other electrical energy storage facilities).

Table 5. Energy Selling Price Determination Regulation

No	Capacity	Highest Benchmark Price (USD cents/kWh)	
		Years 1 – 10	Year 11 – 30 (Max. 30)
1	0 – 1 MW	(10.18 x F)*	6.11
2	>1 MW – 3 MW	(9.81 x F)*	5.89
3	> 3 MW – 5 MW	(8.99 x F)*	5.39
4	>5 MW – 10 MW	(8.51 x F)*	5.10
6	>10 MW	(7.44 x F)*	4.46

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After setting the energy price based on the regulation above, because the generating capacity of the PLTS on Sabira Island is less than 1 MW, then we can determine the energy price with the equation in column 1, using the F factor in the Java, Madura, Bali (Small Islands) region with an F value of 1.1. With a dollar exchange rate of Rp. 16,454, it can be calculated in the equation below.

In years 1 – 10:

$$= 10{,}18\ x\ F$$

$$= Rp\ 1.850{,}47/kWh$$

In years 11 – 25:

$$= 6{,}11$$

$$= Rp\ 1.099{,}68/kWh$$

- Sales Scheme I

Based on electricity sales data on Sabira Island, electricity sales per kWh are Rp. 1,522/kWh. So, based on this price, the energy price in the 1st to 10th year is set at Rp. 1,522/kWh and in the 11th to 25th year it is 1099.68.kWh

Based on the calculation of energy that can be produced in Table 4.5 and the selling price determined by sales data on Sabira Island, then with the energy capacity generated for 25 years is 363.15 MW/Year. Then the income from the 1st to the 10th year is Rp. 5,527,291,134.78 and the income in the 11th to the 25th year is Rp. 5,986,688,196.91.

Table 6. Energy Income and Prices I

Aspect	Mark	Unit
Electricity production (1-25)	363.15	MWh/Year
Energy cost sold (1-10)	Rp1,522	Rp/kWh
Energy costs sold (11-25)	Rp1099.68	Rp/kWh
Income year 1-10	Rp.5,527,291,134.78	Rp/Year
Income year 11-25	Rp. 5,986,688,196.91	Rp/Year
Salvage Value	Rp. 400,000,000	Rp
Tipping fee	Rp. 81,525,487.5	Rp/Year

The initial investment cost consists of the cost of procuring the main system, installation, construction, and supporting components. The following estimate refers to a small-scale PLTSa project (60-80 Kw) commonly used in remote areas, in this case the initial investment value for the construction of PLTSa anaerobic digestion technology is assumed to be 4 billion Rupiah and the Operational and Maintenance Cost Estimation is Rp. 125.000.000, this evaluation uses several important indicator as below

Table 7. Economic and Social Parameter

Aspect	Unit
MARR	6%
Lifetime	25 Years
Depreciation Period	25 Years
Depreciation Cost	Rp144,000,000 / Year
Income Tax	22%
Inflation	1.95%

And with capital structure and financing

Table 8. Capital Structure and Financing

Aspect	Unit
Equity Share	30%
Debt Share	70%
Net Equity	Rp1,200,000,000
Net Debt	Rp2,800,000,000
Loan Payback Time	20 Years
Loan Interest Rate	5.50% / Year

As presented in table we get value of the LCC, LCOE, COE, IRR and NPV

Table 9. Investment Feasibility Result Scheme I

Aspect	Unit
NPV (Net Present Value)	Rp2,502,763,886
IRR (Internal Rate of Return)	4%
DPP (Discounted Payback Period)	17
LCOE	Rp 1.084,4
COE	Rp 768,26

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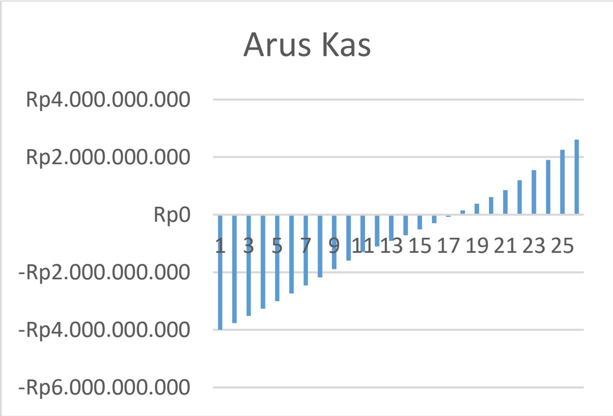

Figure 2. Cash Flow Graph Scheme I

Based on this sales scheme, the project is not financially viable based on MARR, because it means the project generates more money than the investment value but does not meet the minimum expected return required to cover the risk, cost of capital and other investment alternatives.

- Sales Scheme II

Based on the calculation of the maximum value of electricity sales set at 4.6. So, based on this price, the energy price in the 1st to 10th year is set at Rp1,850.47/kWh and in the 11th to 25th year it is 1099.68.kWh.

Table 10. Energy Income and Prices II

Aspect	Cost	Mark
Electricity production (1-25)	363,159	MWh/Year
Energy cost sold (1-10)	Rp1,850.47	Rp/kWh
Energy costs sold (11-25)	Rp1099.68	Rp/kWh
Income year 1-10	Rp. 6,720,161,909.45	Rp/Year
Income year 11-25	Rp. 5,986,688,195.91	Rp/Year
Salvage Value	Rp. 400,000,000	Rp
Tipping fee	Rp. 81,525,487.5	Rp/Year

By using the investment value, operational and maintenance cost value, MARR value, inflation value, interest rate and the same loan term, we get the valueas presented in Tables 11 as below

Table 11. Investment and Feasibility Result Scheme II

Aspect	Unit
NPV (Net Present Value)	Rp3,906,962,974
IRR (Internal Rate of Return)	7%
DPP (Discounted Payback Period)	11 years
LCOE	Rp. 997,19
COE	Rp. 699,4

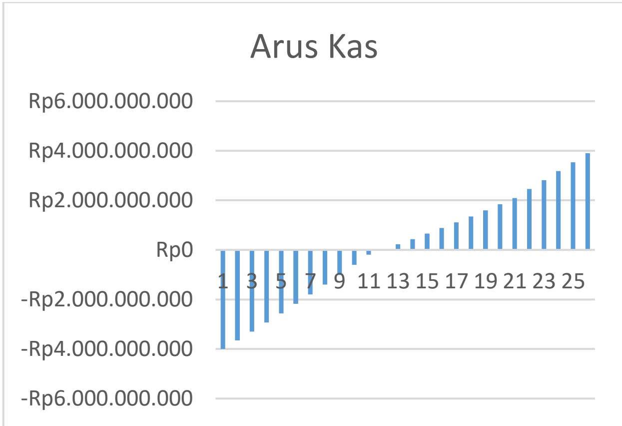

Figure 3. Cash Flow Graph Scheme II

Based on this sales scheme, the project is financially viable based on MARR, because it means the project generates more money than the investment value and also meets the minimum expected return required to cover the risk, capital costs and other investment alternatives.

VI. CONCLUSION

Simulations show that borrowing costs play a major role in determining the financial feasibility of a PLTSa project. The use of low-interest financing schemes such as green financing, grant contributions, or KPBU (Government Cooperation and Business Entity) schemes will make the project more attractive to investors and economically feasible. In addition, renewable energy policies from the government (for example, special feed-in tariffs for green energy subsidies) are highly recommended to support the implementation of similar projects in remote areas.

The results of the economic analysis of the waste-to-energy power plant (PLTSa) system based on anaerobic digestion technology on Sabira Island show that this project has high strategic value from the social, environmental, and energy security aspects, although from a purely financial aspect the project is not yet fully profitable without additional support or a subsidy scheme.

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