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Technical and Economic Review of Biogas Utilization from Traditional Market Organic Waste

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ABSTRACT: This research is a continuation of previous research, namely the Study of the Potential of Gorontalo City Central Market Organic Waste as Raw Material for Biogas Reactors which was completed in 2023 and has produced characteristics of organic waste generation at the Central Market of Gorontalo City. As a continuation of previous research, this research will try to design a Biogas Reactor by utilizing organic waste at the Central Market of Gorontalo City as a traditional market which produces waste every day and is a problem for the city government. The materials used in writing this article are based on the results of research carried out by the author in 2023 from other selected articles related to the use of organic waste as an energy source through the fermentation process in a biogas reactor (digester). From the technical aspect, the research has succeeded in designing a fixed dome type biogas reactor, reactor volume 15.3 m^3 with reinforced concrete construction complete with a cost budget and detailed drawings for its construction. Meanwhile, from an economic aspect, an economic analysis has been carried out and it can be concluded that investment with initial capital of Rp. 78,793,000, economically feasible as indicated by the parameters NPV > 0, IRR (22.22%) > MARR (10.07%), B/C Ratio 2.0 times, and Payment Period 12 years 0 months..

KEYWORDS: design, reactor, biogas, organic waste, economic analysis

I. INTRODUCTION

Energy is one of the main components in a country's economic development and growth. In recent decades, the need for energy sources has increased significantly due to population growth and industrial development. However, the use of fossil fuels as the main energy source has caused various problems, including greenhouse gas emissions, air pollution, and dependence on limited energy supplies [1], [2]. Fossil fuels meet 80 percent of global primary energy needs today, and the energy system is the source of about two-thirds of global CO_2 emissions. Because emissions of methane and other short-lived climate pollutants (SLCP) are believed to be underestimated, it is likely that energy production and use is a larger source of emissions. Additionally, most biomass fuels are currently used worldwide for small-scale heating and cooking. This is very inefficient and causes pollution, especially to indoor air quality in many less developed countries. Research conducted by references [3], concluded that renewable biomass used in this way is a problem for sustainable development. So the government's policy in cofiring Steam Powered Electricity Centre (PLTUs), namely replacing coal, either partially or completely, with biomass material requires caution. The global energy crisis and its negative impact on the environment have prompted various efforts to find sustainable and environmentally friendly alternatives. One interesting alternative energy source is biogas. Biogas is gas produced through the anaerobic fermentation process of organic materials such as agricultural waste, food waste and animal waste [4]. This gas mainly consists of methane (CH_4) and carbon dioxide (CO_2), and can be used to produce electricity, heat, and even as vehicle fuel which can be obtained through the use of organic waste.

Waste has become a problem in society today, especially Indonesia. The increasing volume of waste generated is strongly influenced by several factors, including: population growth, development rate, community socio-economic level, community activities [5], and also waste management patterns which still rely on landfilling at the Final Processing Site (FPS), and according to reference [6] there is still a lack of public awareness in the sorting process and 3R (reduce, reuse and recycle). Refuse Derived Fuel (RDF) of 25.57%. centralized waste separation and processing activities, which are the main tasks of the Integrated Waste Processing Site (IWPS), have not yet been able to function optimally due to the lack of facilities and infrastructure [7].

Gorontalo City, which is the capital of Gorontalo Province, continues to experience development marked by increased economic activity, including the Central Market of Gorontalo City which is a shopping centre for the daily needs of the people of Gorontalo City and its surroundings. Research conducted by references [4] obtained information that vegetables dominate the amount of waste generated at the Central Market of Gorontalo City, namely 74.23% from vegetable waste, followed by fruit waste at 17.12%, and fish/meat waste at 8.65%. If this waste production is used as a source of electrical energy through the use of a biogas reactor, it can produce electrical energy of 5,115.84 kwh per month or the equivalent of the electrical energy used by 30 electricity customers in the 450 VA load category. Implementation of biogas as an energy source has great potential to reduce greenhouse gas emissions, reduce organic waste entering landfills, and increase local energy security. Renewable energy is very important to achieve sustainable and clean electricity generation [8], [9]. Meanwhile, according to research by Refs. [10], [11], among all conventional methodologies for renewable electricity generation, only around 8.3% of renewable energy resources are owned by bioenergy units.

One of the most influential factors in sustainable electricity generation is based on the type of fuel. Based on research conducted by references [10], biogas is an important fuel in producing clean and sustainable electric power. Assessing sustainability requires going beyond conventional environmental life cycle assessments and combining the study of economic aspects with social performance. Apart from the existence of various renewable resources and the perception of environmental friendliness in electricity generation, the rate of electricity production from biogas needs to be known and calculated effectively. Life Cycle Assessment (LCA) is a functional approach used to measure the environmental sustainability of energy systems. Combining various environmental and economic assessment indicators, through standard coverage and models, will provide greater insight into the sustainability of biogas systems [10], [12].

Sustainable electricity generation via biogas is directly influenced by biogas production. According to research by references [13], the sustainability of biogas production is not determined by regional results but by nutritional and operational recovery factors. The raw materials for biogas generators and their availability show the potential for biogas production to be used as an alternative fuel for sustainable electricity generation. Among renewable energy sources, biogas is more adaptable and flexible compared to wind and solar energy, and is more economical because it requires relatively lower capital investment and operational costs which can vary depending on geographic location [10]. The implementation of biogas as an energy source has the potential to be a sustainable solution in overcoming global energy challenges while reducing negative impacts on the environment [14], [15]. This research is a continuation of research conducted by author with technical and economic aspects being the focus of this research.

II. MATERIALS AND METHODS

A. Materials

The materials used in this research are based on the results of research carried out by the author in 2023 and the other selected articles related to the use of organic waste as an energy source through the fermentation process in a biogas reactor (digester).

B. Methods

This research is a continuation of previous research on the potential for waste generation in the Central Market of Gorontalo City which was carried out by the author in 2023. And this article continues by compiling a detailed engineering design (DED) as a technical review and carrying out an economic feasibility analysis as an overview of the use of this type of biogas reactor fixed dome made from organic waste from the Central Market of Gorontalo City.

III. RESULTS AND DISCUSSION

A. Design of Biogas Reactor

1. Calculate the digester volume

The digester volume is calculated based on the potential for waste generation in the Central Market of Gorontalo City as per the results of research conducted by author in 2023. From the research results, data is obtained as in Table 1 as follows:

Table 1. Amount of organic waste per week at the Central Market of Gorontalo City

Week	Vegetables	Fruit	Fish / Meat	Total (kg)
	Amount (kg)	Amount (kg)	Amount (kg)	
I	2311,70	520,90	254,10	3086,70
II	2340,35	542,00	264,00	3146,35
III	2309,80	543,50	280,00	3133,30
IV	2334,60	537,50	286,00	3158,10

The solid content (TS) of organic waste at the Central Market of Gorontalo City was calculated using Eq. (1) based on the characteristics of several biogas raw materials according to references [16] and the results are given in Table 2.

$$TS = TS(\%) \times quantity\ of\ raw\ materials\ (kg) \quad (1)$$

Table 2. Organic waste solids levels per week at the Central Market of Gorontalo City

Week	Solids Content (kg)		
	Vegetables	Fruit	Fish / Meat
I	404,55	91,16	38,12
II	409,56	94,85	39,60
III	404,22	95,11	42,00
IV	408,56	94,06	42,90
Average	**404,55**	**91,16**	**38,12**

Based on Table 2, the total solids content per week is 533.83 kg/week or 78.26 kg/day. Using Eq. (2), the digester volume is calculated as follows:

$$V_R = V \times HRT \quad (2)$$

The volume of substrate fed per unit time [m3/day] is 78.26 kg/day. While the ratio of raw materials to water for biogas from organic materials is 1:2, the volume of substrate fed is 76.26 kg + 152.2 liters or the equivalent of 228.78 liters. With hydraulic retention time (HRT), namely the residence time in the digester for a simple biodigester without heating is 40 days [17], then:

$$V_R = V \times HRT = 228{,}78 \times 40 = 9151\ liter = 9{,}2\ m^3$$

This is a volume of 60% of the total volume of the biogas reactor (digester), so the total reactor volume is: $\frac{9{,}2}{0{,}6} = 15{,}3\ m^3$.

2. Dimensions of raw material space

The total volume of the biogas reactor based on the daily waste generation of the Central Market of Gorontalo City from previous calculations is 15.3 m^3. Meanwhile, the space for raw materials (substrate) is 60% of the total reactor volume, namely 9.2 m^3. If the diameter of the biogas reactor is planned to be 2.5 m, then based on the volume of the raw material chamber, and by using the Eq. (3) to calculate the volume of the cylinder, the height of the raw material chamber *(h_s)* can be calculated as follows:

$$V = \pi r^2 h \quad (3)$$

By changing *V* to V_s (substrate space volume) and h to hs, equation (3) can be written in the form of Eq. (4) to calculate hrs as follows:

$$h_s = \frac{V_s}{\pi r^2} \quad (4)$$

where:

h_s : height of substrate space
V_s : volume of substrate space
r : radius = ½ of the diameter

then the height of the substrate space *(h_s)* calculated using equation (4) is:

$$h_s = \frac{9{,}2}{3{,}14 \times 1{,}25^2} = 1{,}9\ m$$

3. Dimensions of the gas chamber

The biogas reactor designed in this research is a fixed dome type biogas reactor (digester). The main characteristic of a fixed dome type biogas reactor is its cylindrical shape with a top cover in the form of a hemispherical dome. The volume of the gas chamber is obtained from the difference between the total volume of the biogas reactor and the volume of the raw material chamber, namely: $V_{gc} = V_R - V_s = 15{,}3 - 9{,}2 = 6{,}1\ m^3$ where the top of the gas chamber is a hemispherical dome. Therefore, first calculate the volume of a hemispherical gas chamber with a diameter of 2.5 m or radius (r) 1.25 m using the Eq. (5) for calculating the volume of a hemisphere as follows:

$$V_{hemispherical} = \frac{2}{3}\pi r^3 \quad (5)$$

$$V_{gc1} = \frac{2}{3} 3{,}14 \times 1{,}25^3 = 4{,}1\ m^3$$

With a dome volume of 4.1 m^3, there is still 6.1 m^3 – 4.1 m^3 = 2 m^3 *(V_{gc2})* of gas space under the dome. The height of the gas space under the dome can also be calculated using Eq. (4) by changing *hs* to h_{gc2} and V_s to V_{gc2} as follows:

$$h_{gc2} = \frac{v_{gc2}}{\pi r^2} = \frac{2}{3.14 \times 1.25^2} = 0.4\ m$$

4. Dimensions of the fixed dome type biogas reactor (digester)

Overall, the fixed dome type biogas reactor (digester) using organic waste from the Central Market of Gorontalo City consists of 3 segments, namely:

a. Segment for raw material (substrate) room with dimensions: volume 9.2 m^3; height 1.9 m; and a diameter of 2.5 m.
b. The gas chamber segment-1 (g_{c1}) has the shape of a hemispherical dome with dimensions: volume 4.1 m^3; height 1.25 m; and a diameter of 2.5 m.
c. The gas chamber segment-2 (g_{c2}) has the shape of cylindrical is under a hemispherical dome with dimensions: volume 2 m^3; height 0.4 m; and a diameter of 2.5 m.

More details about the dimensions of this biogas reactor are shown in Figure 1 below:

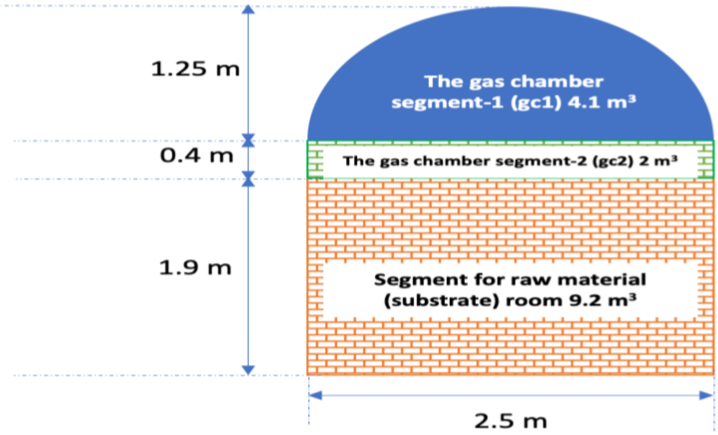

Figure 1. Organic waste solids levels per week at the Central Market of Gorontalo City

5. Inlet, outlet, and storage for solid and liquid waste

The inlet and outlet channels use 10" PVC pipe with the placement of the holes for the inlet and outlet just below the upper limit of the raw material space (substrate). The outlet channel is connected to the solid waste reservoir, and then connected to the liquid waste reservoir. Solid waste and liquid waste storage facilities are in the form of a box with a rectangular cross section (1 m x 1 m) and a height of 1.5 m.

6. Gas hose

The gas hose used is ½ inch, and the length is adjusted to the conditions/needs in the field. In this gas line, a purification device and measuring the volume of gas passing through the gas hose are also added.

7. Biogas Reactor Construction

The fixed dome type biogas reactor is made from reinforced concrete with a thickness of 10 cm. To reduce the risk of leaks, both sides, both the inside and outside of the biogas reactor, are plastered and coated with leak-proof material/paint. The design of the fixed dome biogas reactor is shown in Figure 2 below:

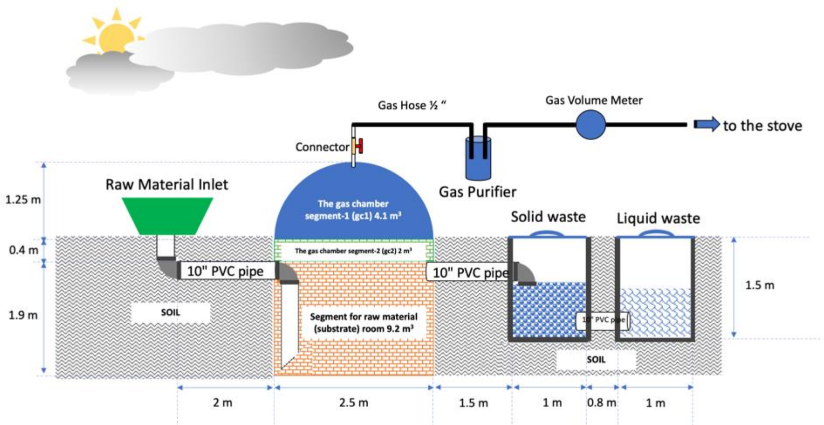

Figure 2. Biogas reactor series at the Central Market of Gorontalo City

8. Cost Budget

The cost budget is calculated based on design drawings, volume, materials, and wages in accordance with the Work Unit Price Analysis (WUPS) coefficient which is regulated based on the Indonesian National Standard [18] which is related to civil construction work, as for the price of materials and workers' wages based on the Gorontalo Governor's Regulation Number 48 of 2021 concerning Regional Unit Price Standards for the 2022 Fiscal Year as stated in the document [19]. From the calculation results, the budget for the biogas reactor based on the organic waste potential of the Central Market of Gorontalo City is IDR. 78,793,000,-.

B. Economic Analysis

Based on the cost budget, an economic analysis is then carried out to calculate the economic feasibility parameter values, namely Internal Rate of Return (IRR), Benefit Cost Ratio (B/C Ratio), Net Present Value (NPV), and Payback Period (PP), with the following assumptions used in economic analysis as follows:

1) Capital (P).
   Capital or investment is obtained from the budget plan as follows: Rp. 78,793,000,-
2) Interest rate (i).

The interest rate is the average bank interest rate from various types of banks in Indonesia as of June 2023 at the time the research was conducted, namely = 10.07%. This bank interest rate is also assumed to be an appropriate Minimum Attractive Rate of Return (MARR) so that a profit will be obtained from the investment project. If an IRR is obtained that is less than or equal to the MARR, then the capital investment project is not feasible to be realized. If the IRR obtained from a capital investment or investment project is greater than MARR, then the project is worthy of realization.

3) Loan period (financial criteria).

The loan period or financial criteria is 15 years which is based on the minimum age of the digester, which is 10 years and the maximum is 20 years [20].

4) Gas production per day.

Gas production is assumed to be the same as the volume of the gas chamber in the biogas reactor (digester), namely 9.2 m3 which will be full in 40 days (HRT period, Hydrolic Retention Time) or the equivalent of 5.1 kg of methane per day or 1861.5 kg per year. If the price per kg of methane gas is equivalent to LPG per kg, namely Rp. 17,167,- then 1861.5 kg = Rp. 31,955,750.0 per year.

5) Operational costs per year (Annual Operation Cost).

This cost is obtained from labor costs and is assumed to be Rp. 2,291,368,- per year, and is considered constant over the loan period, which is 15 years.

The results of the economic analysis of a fixed dome type biogas reactor made from organic waste from the Central Market of Gorontalo City are given in Table 3 below:

Table 3. Organic waste solids levels per week at the Central Market of Gorontalo City

Resume of the Economic Feasibility			
Initial investment		78.793.000	Rp
Investment Period		15	years
Average Annual Revenue		31.955.750	Rp
MARR = i		10,07	%
1	*NPV*	66.086.320	> 0 Rp
2	*IRR*	22,22%	> MARR (10,07%)
3	*B/C Ratio*	3,86	*times (without discount factor 10,07%)*
		2,00	*times (with discount factor 10,07%)*
4	*Payback Period*	*7 years 8 months*	*without discount factor 10,07%*
		12 *years* 0 *months*	*with discount factor 10,07%*

The economic feasibility analysis as given in Table 3 can be explained as follows:

1. Net Present Value (NPV)

Net Present Value (NPV) is a method that calculates the difference between benefits or receipts and costs or expenses, or the difference between the present value of an investment and the present value of all net cash receipts in the future. Investment appraisal using the NPV method is usually used if the cost of capital of the investment is known and the required return expected by the investor for their investment plan has been determined [21]. From the results of calculations with an interest rate of 10.07% and the assumption that operational costs are the same every year, the NPV value is Rp. 66,086,320,- over a 15 year period. This means that the value of profits obtained from the use of biogas reactors in the next 15 years is equivalent to a monetary value of Rp. 66,086,320,- currently. In general, the NPV criteria says that a project will be worth choosing if the NPV value is > 0. On the other hand, if a project has an NPV < 0, it will not be chosen because the project is not worth running. Based on the NPV calculation, investment in a fixed dome type biogas reactor using organic waste as raw material from the Central Market of Gorontalo City is economically feasible.

2. Internal Rate of Return (IRR)

It is the level of margin/fee/profit sharing that makes the total present value of expected proceeds (PV of future proceeds) equal to the total present value of capital expenditures (PV of capital outlays) [21]. An investment project is considered profitable if the IRR is greater than the desired margin/fee/profit sharing level or IRR > cost of money (risk level + SWBI or in this research is MARR, equal to 10.07%). From the IRR calculation results, a value of 22.22% was obtained, or greater than MARR (10.07%), so based on the IRR assessment, investment in a fixed dome type biogas reactor using organic waste as raw material from the Central Market of Gorontalo City is economically feasible.

3. B/C Ratio

Investment project assessment based on benefit cost ratio (B/C Ratio) is a method of assessing investment projects using measurements; comparison between benefits or present value of proceeds with present value costs or present value of capital outlay [21]. An investment project is said to be economically feasible if the comparison produces a minimum value of 1 or PV Proceeds/PV Capital Outlay > 1. Based on the calculation results, the B/C Ratio = 3.86 without df factor (without discount factor 10.07%) and 2 .0 with df factor (with discount factor 10.07%). This means that the profit on investment is 3.86 times without the df factor (without discount factor 10.07%) and 2.0 times with the df factor (with discount factor 10.07%). Thus, investment in a fixed dome type biogas reactor using organic waste as raw material from Central Market of Gorontalo City is economically feasible.

4. Payback Period

Payback Period is the period required to recoup investment expenditure (initial cash investment) or the return period for the investment that has been made, through profits obtained from a planned project. According to Ruminta [21], the payback period is the period required to be able to recoup investment expenditure using proceeds or net cash flows. From the calculation results, it was found that the Payback Period for investing in a fixed dome type biogas reactor using organic waste as raw material at the Central Market of Gorontalo City is 7 years 8 months without the df factor (without discount factor 10.07%) and 12 years 0 months with the df factor (with discount factor 10.07%). This means that this investment will be able to return capital within a period of 7 years and 8 months without the df factor (without discount factor 10.07%) and 12 years 0 months with the df factor (with discount factor 10.07%), or with In other words, it does not exceed the loan period, namely 15 years. Thus, investment in a fixed dome type biogas reactor using organic waste as raw material from Central Market of Gorontalo City is economically feasible.

IV. CONCLUSIONS

In the context of implementing biogas as an energy source, a number of technical aspects must be considered. First of all, the biogas production process must be optimized to maximize methane production. This involves selecting the appropriate type of organic material, setting optimal fermentation conditions, and efficient waste management. In addition, biogas storage and distribution technology is also important to ensure a stable supply. The biogas utilization system must also be designed well. Biogas can be used to produce electricity, heat, or used as fuel in vehicles. Therefore, the selection of appropriate technology and appropriate arrangements must be taken into account to meet energy needs efficiently.

From an economic perspective, the implementation of biogas as an energy source has the potential to provide significant economic benefits. First of all, biogas can help reduce energy costs, especially in the agricultural and industrial sectors. Apart from that, biogas production can also create new business opportunities, such as producing organic fertilizer from fermentation residue. However, there are also costs associated with biogas implementation, including the initial investment in infrastructure and equipment, as well as operational and maintenance costs. Therefore, a careful economic analysis needs to be carried out to evaluate the economic feasibility of a biogas implementation project. In addition, factors such as government support policies, conventional energy prices, and potential income from the sale of biogas energy also need to be taken into account in the economic assessment.

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