Strategic Model of Sustainable Program A Conceptual Framework for Hybrid Energy Implementation inCompanies Using Biogas as an Energy Source

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ABSTRACT

The framework of the methodology presented in this study is an effort to integrate and optimize the agroindustry sector, especially energy in biogas. In this study, the technique of the system in functional analysis is shown systematically to translate various energy requirements in the factory as criteria for performance and functional design to be integrated, optimized, and energy efficient. The case study results indicated that PLTBg, with a capacity of 1.5 MW, can produce around 1.5 MW = 13,140 MWh per year. The annual return on investment (ROI) is around 37.13%. With this ROI value, the payback period is 31 months. The overall reduction of greenhouse gases is approximately 77,826 tons CO2 eq/year. The potential value of carbon trading is about USD 3,113,040 per year. This strategic model presents a novel approach by integrating biogas energy production with a customized wastewater treatment system adapted to biodigesters' effluent characteristics. It offers a sustainable, economically feasible, and scalable solution, combining resource recovery, waste minimization, and potential for carbon trading into a unified system. The novelty of this research lies in maximizing the utility of biogas plants by efficiently treating and reusing wastewater, creating a closed-loop, zero-waste process. Future research on hybrid systems integrating PLTBg by focusing on efficiency optimization, economic feasibility, environmental impacts, and innovative approaches like AI and blockchain could make the hybrid system a more robust, scalable, and sustainable solution. Thus, the framework based on the results of this study finds tools that can maximize and integrate energy sources, especially biogas, in the agro-industrial sector.

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1. INTRODUCTION

In recent years, renewable energy has become a significant focus for many countries in their efforts to reduce dependence on fossil energy sources and reduce carbon emissions. One form of renewable energy that is becoming increasingly popular is biogas, which can be produced from organic waste, such as animal manure, agricultural waste, and household waste (Ahmadi-Pirlou & Mesri Gundoshmian, 2021; Chatterjee et al., 2019; Mohanty et al., 2022; Pelayo Lind et al., 2021). Biogas Power Plant (PTBg) is a technology that utilizes biogas to generate electricity (Aguilar-Virgen et al., 2014; Dodo et al., 2022; Olujobi, 2020; Sodri & Septriana, 2022). This article will compare the electricity used by PTBg and electricity from the State Electricity Company (PLN) in Indonesia, focusing on savings and efficiency.

Climate change is still a significant concern in both global and national contexts. The international community has committed to reducing greenhouse gas (GHG) emissions. In 1992, it was codified in the United Nations Framework Convention relating to the ongoing existence of Climate Change. (Aggarangsi et al., n.d.; de Oliveira et al., 2021; Karimi et al., 2023; Yang et al., 2023). Through Law No. 6 of 1994, Indonesia has ratified the UNFCCC. Then, in Indonesia, through Law No. 17 of 2004, this framework was followed by the Kyoto Protocol in 1997, which was adopted ten years later. The law affirms that as one of Indonesia's critical players involved in addressing the challenges posed by climate change, its extensive forests are vital for carbon sequestration, including its natural resource potential. In 2011, in the Presidential Decree contained in number 61 of 2011 related to the Planning of National Action on GHG Emission Reduction (known as RAN-GRK), the target of reducing GHG emissions by 26% by 2030 compared to the baseline was proclaimed (Guo et al., 2021; Malahayati & Masui, 2021; Suhartini et al., 2021; Walker et al., 2018). RAN-GRK requires every province in Indonesia, including stakeholders and local governments, to actively contribute to local actions by implementing a participatory approach.

PTBg is a system that converts biogas into electrical energy. Biogas can be defined as a mixture of methane gas (CH4) and carbon dioxide (CO2), which is initially sourced from the anaerobic fermentation process (without oxygen) of organic matter by various types of microorganisms (Armawi & Martono, 2016; Proyek, n.d.; Siregar, 2018; Suhartini et al., 2022; Sunanda & Kurniawan, 2018). This process can occur in a biogas digester, a closed reactor designed to facilitate the fermentation of organic matter such as livestock waste, plant residues, or household waste.

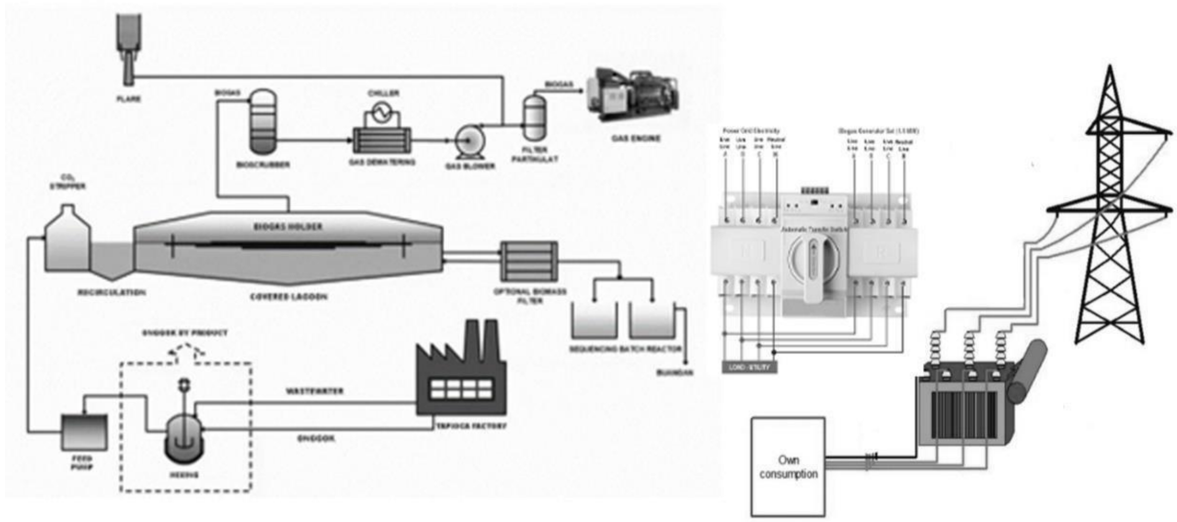

Figure 1 Hybrid Biogas Energy Production System

Digesters that produce a variety of biogas can be used by humans as fuel for power plants so that they can produce electricity. PTBg can be used on a small scale for the needs of households or local communities (Chavalparit & Ongwandee, 2009, 2009; Jarwar et al., 2023; Petravić-Tominac et al., 2020), as well as on a large scale to meet industrial or commercial electricity needs.

The implementation of a hybrid energy strategy that combines electricity from PLN with Biogas Power Plants (PLTBg) is one of the solutions to overcome the instability of electricity supply, especially in island areas that are far from energy distribution centers (Banu et al., 2006; Cherukuri & Parthasarathy, 2023; Dodo et al., 2022; Govindradjane, 2023). This hybrid system not only improves the stability of the electricity supply but also supports energy sustainability through utilizing local resources, such as agricultural and livestock waste.

However, until now, there has been a need for adaptation from the framework to integrate energy into the agroindustry. This research aims to fill in the gaps in knowledge based on the following questions:

(1) How to systematically identify leverage points in an agro-industry for simultaneous integration of biogas energy and on-grid power energy source;

(2) How to integrate biogas energy in a way that optimizes the overall energy efficiency of the industrial plant.

This research mini article was made to produce a conceptual framework that allows simultaneous optimization in factories in the agro-industrial sector, especially hybrid biogas energy. This research sustainably obtains energy availability to process and reduce energy needs locally and internationally. The study will discuss the implementation of biogas-based hybrid energy projects, explore the hybrid system models used, and analyze the results, including cost savings, contribution to carbon emission reduction, and the resulting socio-economic impact on local communities.

2. MATERIAL AND METHOD

2.1. Conceptual framework integrating hybridized biogas energy

Developing models of activities to optimize energy in industrial plants, especially hybridized biogas energy, has become a conceptual framework for research. This framework flow is implemented before investmentdecisions in renewable energy are implemented. This is summarized in Fig. 2.

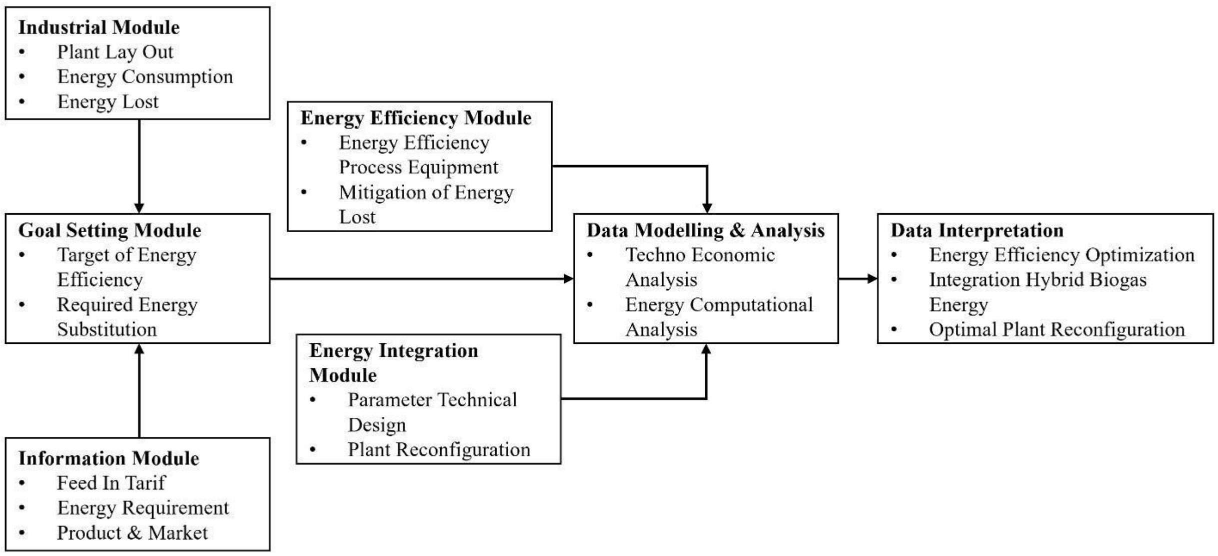

Figure 2 Framework Integration Hybrid Biogas Energy

The development of seven modules as a reference in the conceptual framework (Grohmann et al., 2018; Shih etal., 2023; Zhang et al., 2022):

Industrial module, goal setting, Modules from various types of industries, in setting the objectives of the module, modules used as information, modules as a reference for energy efficiency, modules as the integration of energy, modeling on various data, analysis on modules, and data interpretation in modules. The conceptual framework design is modeled almost the same as the methodology by Fu et al. (Grohmann et al., 2018; Shih et al., 2023; Zhang et al., 2022), namely to model the existence of an effective and efficient information process in the financial supply chain in the industrial sector (Osman et al., 2022).

A detailed description of each module with practical illustrations of the agro-industrial plant follows.

2.1.1 *The industrial plant module*

If the purpose of re-registration has been determined, which is then documented, the next is the module stage of the industrial factory as a framework for all human activities in the factory (Osman et al., 2022). The objectives of this module are (a) to understand and map the layout of a factory as the most important unit operation;
(b) to determine the form of the type of energy in the hydro, heat, or electricity plant; (c) Measuring the use of energy in water, heat, or electricity generation; and (d) Determining energy losses for hydro, heat, or electricitygeneration.

Table 1. shows historical data on the energy distribution in percentage for different unit

operations in anagroindustry plant. Please note that the exact percentages can vary depending on the specific plant's configuration and energy efficiency, but these data can give a general idea of the same process.

Table 1. Data on the energy distribution in percentage

Unit Operation	**Type of Energy Used**	**Energy Percentage (%)**
Peeling	*Mechanical (Electricity)*	5%
Washing	*Mechanical (Water and Electricity)*	10%
Grinding	*Mechanical (Electricity)*	15%
Sieving	*Mechanical (Electricity)*	10%
Extraction	*Mechanical (Electricity)*	10%
Dewatering	*Mechanical (Electricity)*	10%
Drying	*Thermal (Heat from Steam/Electricity)*	30%
Milling	*Mechanical (Electricity)*	5%
Packaging	*Mechanical (Electricity)*	5%
	Total	100%

2.1.2 *Information module*

If the operation process in all units related to energy sourced from the plant has been analyzed and documented, the next stage is the information module contained in the framework (Haryanto, 2017; Kurniawan et al., 2021; Saad et al., 2023; Tencent Research Institute et al., 2021). Data regulations can interpret this to external information sources to optimize hybrid biogas types' efficiency and energy integration. This is related to (a) the existence of feed-in tariffs on types of renewable energy at the plant operation site, (b) the existence of essential needs related to theoretical energy, which is sourced from the difference in unit operation (UO), including in the layout of the plant; and (c) the existence of knowledge products and markets with the aim of UO differences about the efficiency of energy. The importance of product and market knowledge is very urgent as optimizing the efficiency of energy contained in the factory is carried out to replace UO, which is no longer an energy-saving technology.

2.1.3 *The goal-setting module*

The first stage is the module that sets goals as a framework. (Gernert et al., 2023; Tian et al., 2021; Zarrinpoor, 2023). This step determines the energy efficiency target and the need to disconnect from the percentage level in energy substitution, including biogas energy. Generally, these decisions are used in projects related to operators and energy engineers in the plant management sector. Improvement of energy efficiency and replacing energy used in gas energy are goals for agroindustrial crops. The purpose of this module is to create a guide to theentire process.

2.1.4 *The energy efficiency module*

The methodology of the energy block guides this study based on previous research by Baniassadi et al. (2015) (Jha & Tripathy, 2021). So, the second stage, a module, is related to energy efficiency as a framework. This stage is associated with a person's activities in conducting audits and optimizing the level of energy efficiency in the factory area. Consideration is made in this module to maximize energy efficiency, including using various toolsin the energy-saving flow, minimizing the occurrence of energy shortages from units in water, heat, or electricity plants, and integrating unit operations on water, heat, or electricity plants. In all these aspects, the researcher considers the days for operating units in water, heat, or electricity plants related to the factory layout, especially inagro-industry. Then, it is described in the discussion of this research. After that, optimization was carried out on the system guided by the theory of Malvin et al. (2014) (Chavalparit et al., 2015; Wee et al., 2017) with a simultaneous anaerobic bioreactor unit based on the theory from Dias et al. (2012).

2.1.5. The energy integration module

The third stage is to optimize energy efficiency as a framework. This stage is urgent in integrating the energy system, especially biogas energy. (Dodo et al., 2022; Farghali et al., 2022; Maeanti et al., 2013; Rodriguez et al., 2019; Serdjuk et al., 2018). Researchers have considered the flow at this stage, including reconfiguration inthe factory, geographical parameters, and technical design specifications. The flow of methodological work development is in Figure 2. Figure 2 consists of activities (illustration in the middle square in Figure 2), inputs to perform activities (illustration in the left square in Figure 2), and output from the completion process in each activity that has been carried out (illustration in the correct square in Figure 2). Suppose there is a failure to achievethe previously set goals. In that case, it is necessary to repeat the application of the feedback loop in certain activities until the goals can be achieved efficiently and optimally.

2.1.6. Data modeling and analysis module

The third stage is a module on modeling and data analysis as a framework. This is a stage that is so urgent in calculating and collecting research data that has been carried out. The analysis carried out by the researcher is related to the feasibility of techno-economy and energy analysis on computing tools. System Advisory Model (SAM) (Goel & Sharma, 2019; Testa et al., 2022), performance models, and financial models are the researcher's considerations in this research case study. However, SAM is not used as a performance consideration, and estimated energy cost expenditure refers to the installation costs, parameters, and operation of the model design asinputs to the model (Kreuger et al., 2022). The researcher used SAM in this study as a cost and performance analysis related to renewable energy projects assisted by computer models in Figure 3 below.

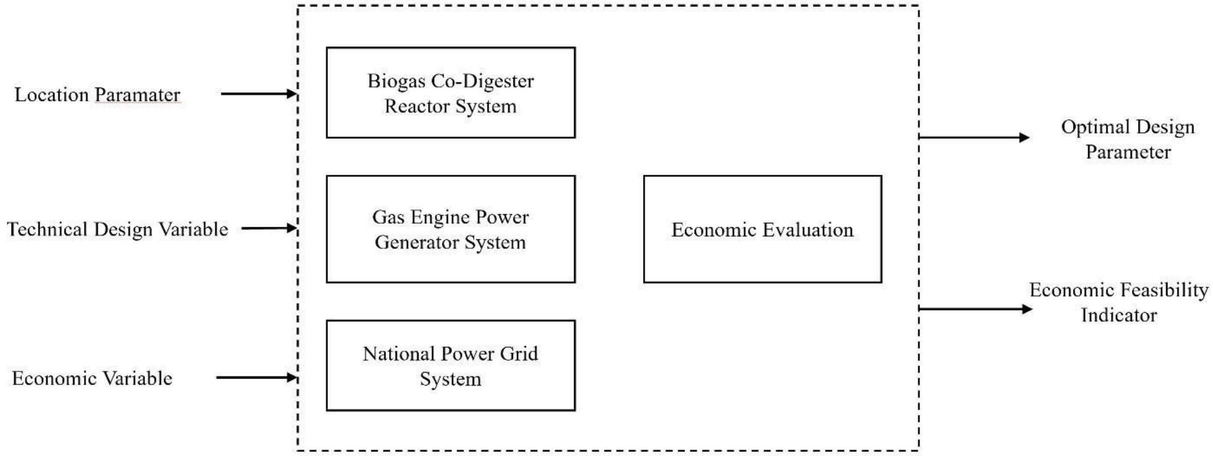

Figure 3. Schematic representation of the System Advisory Model for the hybridized biogas energy model Figure 3 above shows the input parameters for the biogas energy model. Resource data from biogas energy at this research site is already available at SAM. However, the determination of the biogas bioreactor module and the ATS parameters refers to the researcher's experience. The first parameter in system design is related to the alternating current in the air conditioner, the land use, the configuration for electricity, and the size of electricity. The number of cases is low because the location on the system is empty. The selection of the period for a quarter of a century is in line with the next module of the biogas reactor. System-based cost design refers to data obtained from the local market. From the past until now, there have been no incentives nationally for the benefit of the commercial biogas system. Electricity tariff costs refer to Indonesian regulations, especially from the Indonesian Public Utilities Regulation Commission. The determination of the electricity load refers to the rate of accumulation of eight percent in 12 months, which aligns with the projected growth level of electricity demand nationally.

2.1.7 The data interpretation module

The fourth stage is a module on data interpretation as a framework. This stage urgently translates the theoretical results to the recommendation for all vis-à-vis plants to optimize energy efficiency, integrate energy, especially in hybrid biogas, and reconsider the plant. The researcher used the Functional Analysis System (FAST)technique to measure this study's framework (de Almeida et al., 2022; Engel et al., 2019; Sanz & Köchling, 2019). FAST functions in understanding the process of each component thoroughly from the framework, so it is expected to provide value related to optimization for energy efficiency and integration of solar energy at the plant site that produces bioethanol. The advantage of using this approach is that FAST is proven to help humans solve research problems in a clear, systematic, effective, and efficient manner related to many functions in the system so that it gives rise to a logical relationship between functions and technological solutions. FAST is illustrated in the resultsand discussion section.

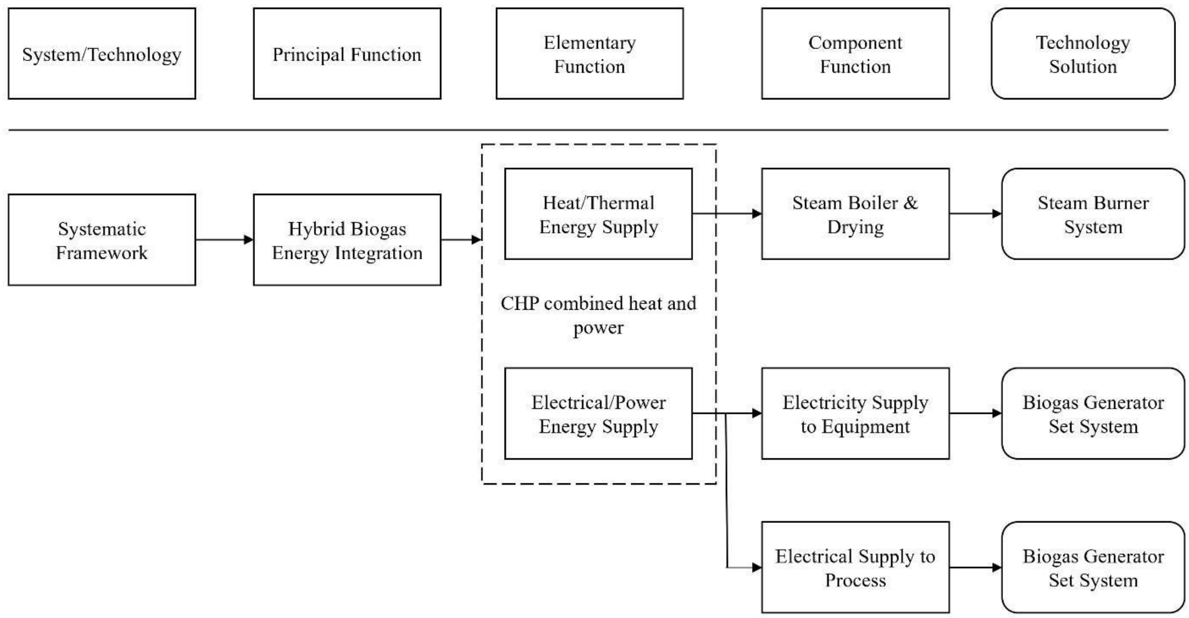

Figure 4. Functional Analysis System Technique of the Framework

2.2. *Automatic Transfer Switch (ATS) Module*

The technology used for the hybrid synchronization of electrical energy (Benti et al., 2021; Sandhu & Kaushal, 2022) between the Biogas Power Plant (PLTBg) and the PLN network involves various modern systems and components. Synchronization in this hybrid energy system is essential to ensure that the electricity generated from PLTBg can run in parallel with electricity from PLN without disturbing grid stability.

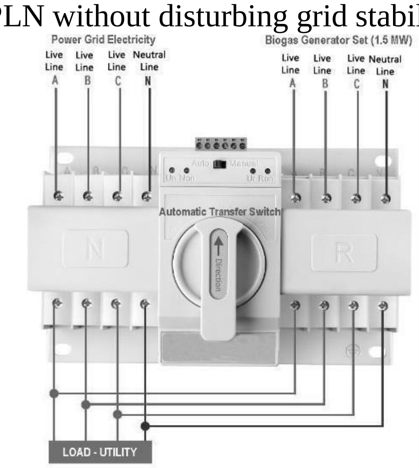

Figure 5. Automatic Transfer Switch (ATS) Model

This study uses an Automatic Transfer Switch (ATS) to auto to switch between the electricity supply from PLTBg and PLN; automatically, if electricity from PLTBg is disrupted or the capacity decreases, the ATS will divert the electricity supply to the PLN network without cutting off the electricity flow to the production system. Once the production from PLTBg is stable again, ATS will return the electricity supply from PLTBg to the production system. This is summarized in Fig. 3 and Fig.4.

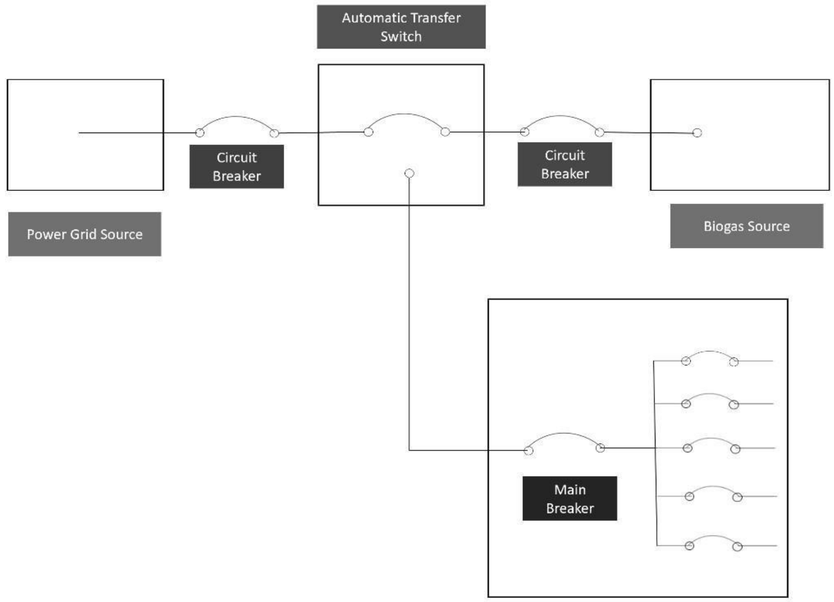

Figure 6. Wiring automatically switches between electricity supply from PLTBg and PLN

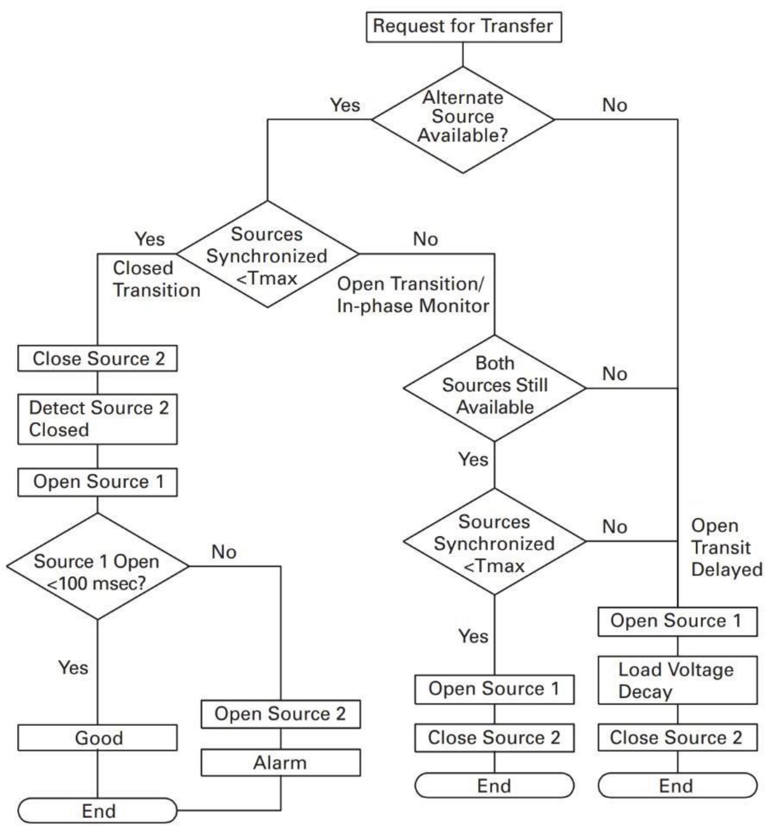

Figure 7. Transfer controllers for synchronization of voltage and frequency

In the application of the system, a synchronizing panel is also used. It is a panel that regulates the synchronization between the electricity flow from PLN and the biogas generator, especially in applications where both power sources must work simultaneously or in situations where the load must be distributed between the two sources. The panel is equipped with a variety of gauges and controllers to ensure the voltage, frequency, and phase of the two power sources are in sync.

Figure 8. Synchroscope for synchronization of voltage and frequency

Figure 8. Show a synchroscope is a tool used in an electric power system to synchronize a generator or alternator with an existing power grid. The synchronization process is essential to ensure that the frequency, voltage, and phase angle of the generator to be synchronized are in line with the network so that safe and stable operation can be achieved.

3. RESULT AND DISCUSSION

Although PTBg requires a considerable initial investment to build infrastructure such as biogas digesters and power generators, this investment can provide significant savings in the long run. PTBg users can enjoy cheaper or even accessible electricity once the initial investment cost is covered.

Meanwhile, PLN electricity requires constant costs during use, with rates that can fluctuate according to government policies and fluctuations in fuel prices. Therefore, for those with access to abundant organic matter sources, PTBg can be a more economical option in the long run.

3.1. The initial investment in PLTBg

The initial investment in the construction of a PLTBg usually consists of several main components,namely in Table 2. The following is historical of the initial investment cost for PLTBg with a capacity of 1.5 MW.

Table 2 Components in the initial investment in PLTBg

No	Components	Details	Exp.
1	*Construction and Infrastructure Costs*	*Digester biogas (reactoranaerobe)* *Piping and gas treatmentsystems* *Electric generator* *Energy storage system(optional)* *Heating or cooling systems required for the*	*Covered Lagoon Bioreactor* *GE Jenbacher*

		fermentation process	
2	*Machine and Equipment Cost*	*Gas engine engine (biogaspower generator)* *Gas purifier (biogas purifier)*	*GE Jenbacher*
3	*Installation Cost*	*Labor and construction costs*	
4	*Land Cost*	*Purchase of land or lease of* *land for plant installation (Ifany)*	
5	*Licensing and Administration Fees*	*Licensing and certifications*	

Table 3 shows investment cost components based on existing market prices and historical data from previous PLTBg projects. As shown in Table 2 following;

Table 3 Investment cost components

No	Cost Component	Estimated Cost (USD)	Exp.
1	*Digester biogas*	*USD 1.000.000*	*Kurs US Dollar*
2	*Biogas power generator*	*USD 750.000*	
3	*Gas purifiers and gas treatment systems*	*USD 300.000*	*1 USD = **Σ Rp** 15.000*
4	*Installation and labor costs*	*USD 400.000*	
5	*Infrastructure and supporting facilities*	*USD 250.000*	
6	*Land (optional, if purchased)*	*USD 200.000*	
7	*Licensing and certification*	*USD 50.000*	
	Total Initial Investment Cost	***USD 2.950.000***	

3.2. PLTBg Operational Costs

In this study, the operational costs of PLTBg were found to include; maintenance and maintenance of equipment (e.g. generator machines, gas treatment systems), labor costs to run daily operations, raw material costs (although biogas usually comes from organic waste, there are still collection and processing costs) (Butemann & Schimmelpfeng, 2020; Cahyani et al., 2019; Nasution et al., 2018; Suwanasri et al., 2015;Wijesinghe et al., 2019). What can be conveyed in the Table

Annual operating costs are usually estimated at around 3-5% of the total initial investment cost.Table 4. Operational Component in PLTBg

No	Operational Components	Estimated Annual Cost (USD)	Exp.
1	*Equipment maintenance*	*USD 100,000*	*Kurs US Dollar*
2	*Labor and operational costs*	*USD 50.000*	
3	*Raw material collection and processing*	*USD 30.000*	*1 USD = **Σ Rp** 15.000*
	Total Annual Operating Costs	***USD 180.000***	

3.3 Revenue and Savings

PLTBg, with a capacity of 1.5 MW, can produce about 1.5 MW × 24 hours × 365 days = 13,140 MWh per year, assuming operating 24 hours a day all year round.

Electricity tariffs in Indonesia vary, but to calculate the return on investment, we can use an average industrial electricity tariff of around USD 0.10 per kWh (USD/kWh). So, the potential annual revenue from electricity sales or electricity cost savings is:

13,140 MWh × 1,000 = 13,140,000 kWh (kWh generated per year)13,140,000 kWh × USD 0.10/kWh = USD. 1,314,000 (annual revenue/savings)

3.4. Return on Investment (ROI)

Return on Investment (ROI) is a measure of performance to evaluate the efficiency or profitability of an investment and to compare the efficiency of several diverse investments (de Almeida et al., 2022; Hasan et al., 2023; Kurochkin et al., 2019). ROI is calculated by comparing the profit or profit earned from the investment with the cost invested. ROI is expressed as a percentage and shows how well an investment makes a profit relative to its price.

Formula to calculate ROI namely:

$$\text{Return On Investment (ROI)} = \frac{\text{Annual Revenue} - \text{Annual Operating Costs}}{\text{Initial Investment}} \times 100\%$$

By entering the calculated value,

$$\text{Return On Investment (ROI)} = \frac{\text{USD } 1.314.000 - \text{USD } 200.000}{\text{USD } 3.000.000} \times 100\%$$

Return On Investment (ROI) =37,13%

This means that the annual ROI is around **37.13%.** With this ROI value, the payback period can becalculated by the following formula;

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Annual Revenue} - \text{Annual Operating Expenses}}$$

Payback Period = USD 3.000.000

USD 1.114.000
≈ 2.7 years

The conclusion that can be drawn is that the initial investment for a 1.5 MW capacity PLTBg ranges from USD 2,950,000 with annual operating costs of around USD 180,000. The ability to generate yearly income/savings from electricity generated is estimated at USD 1,314,000. The annual Return On Investment (ROI) obtained is around 37.13%, with a payback period of around 2.7 years. In the long term, PLTBg, with a capacity of 1.5 MW, can be a profitable investment in terms of saving electricity costs and contributing to carbon emission reduction and environmental sustainability.

The estimated greenhouse gas (GHG) reduction from Biogas Power Plants (PLTBg) with a capacity of
1.5 MW can be calculated based on greenhouse gas emissions avoided by replacing fossil fuel power plants (e.g., coal or natural gas) with renewable energy such as biogas.

3.5 Estimated Emissions Avoided by PLTBg Electricity Production of 1.5 MW

To calculate the emissions avoided (Siddiki et al., 2021), it must first calculate the amount of energy produced by a 1.5 MW PLTBg in a year. Assume that PLTBg operates 24 hours a day and 365 days a year:

Annual Electricity Production = 1.5 MW×24 hours/day×365 days/year Annual Electricity Production = 13,140 MWh/year

3.5.1 Estimated Greenhouse Gas Emissions from Fossil-Based Power Plants

The average CO2 emissions from fossil fuel power plants (mainly coal) are about 0.9 tons of CO2 per MWh of electricity produced. Therefore, CO2 emissions that can be avoided by replacing fossil fuel plants are;

Avoided CO2 Emissions	= Annual Electricity Production × GHG Emissions per MWh
Avoided CO2 Emissions	= 13,140 MWh/year×0.9 tons CO2/MWh
CO2 Emissions Avoided	= 11,826 tons of CO2/year

3.5.2. Reduction of Methane (CH_4) Emissions from Waste Treatment

In addition to reducing emissions from fossil electricity substitution, PLTBg also reduces methane (CH_4) emissions (Carchesio et al., 2020; Olatunji et al., 2022), which is a greenhouse gas with a global warming potential (GWP) twenty-five times greater than CO2. The organic waste treated in the biodigester produces biogas, mainly methane. If organic waste decomposes naturally without being treated in a biodigester, methane will be released into the atmosphere.

3.5.3 Estimated Reduction of Methane Emissions

Based on average assumptions, one m³ of biogas contains about 60% methane and produces 2 kWh ofelectricity.

- **Volume of biogas produced per year:**

$$\text{Biogas per Year} = \frac{13{,}140 \text{ MWh/year}}{2 \text{ kWh/m}^3} = 6{,}570{,}000 \text{ m}^3 \text{ of biogas/year}$$

$$\text{Methane Contained} = 6{,}570{,}000 \text{ m}^3 \text{ of biogas} \times 0.6 = 3{,}942{,}000 \text{ m}^3\ CH_4\text{/year}$$

- **The weight of methane per 1 m³** CH_4 weighs about 0.67 kg.

Avoided CH_4 weight = 3,942,000 m³×0.67 kg/m³ = 2,640,140 kg CH_4/year=2,640 tons CH_4/year

- **Global Warming Potential (GWP)** CH_4

Because methane has a global warming potential as much as twenty-five times greater than CO2 (Lerdlattaporn et al., 2021; Singh et al., 2021), then the determination of the reduction of methane emissions is asfollows:

GHG reduction from CH_4 = 2,640 tons of CH_4× 25 = 66,000 tons of CO2 eq/year

3.5.4. Total GHG Emission Reduction

The total reduction in greenhouse gas emissions from PLTBg consists of reducing CO2 emissions from fossil-based power plants and reducing methane emissions from waste treatment can be estimated as follows:

Total GHG Reduction = CO2 Emissions Avoided from Electricity + GHG Reduction from CH_4 Total GHGReduction = 11,826 tonnes CO2/year + 66,000 tonnes CO2 eq/year
Total GHG Reduction = 77,826 tons CO2 eq/year

The conclusion is that PLTBg, with a capacity of 1.5 MW, can reduce greenhouse gas emissions by 77,826 tons of CO2 equivalent per year. This reduction comes from 11,826 tonnes of CO2 per year avoided from fossil fuel-based electricity substitution and 66,000 tonnes of CO2 equivalent per year avoided from treating methane generated from organic waste. This potential emission reduction shows that PLTBg produces renewable energy and contributes significantly to climate change mitigation.

4. Total Reduction in Greenhouse Gas (GHG) Emissions

To calculate the potential value of carbon trading from a 1.5 MW Biogas Power Plant (PLTBg), we need to correlate the amount of greenhouse gas (GHG) emission reductions calculated pre-calculated with the carbon price in the carbon market. Based on previous calculations, a 1.5 MW PLTBg can reduce emissions by 77,826 tons of CO2 equivalent (CO2 eq) per year. These figures include:

- 11,826 tons of CO2 eq from fossil fuel-based electricity substitution.
- 66,000 tons of CO2 eq from the reduction of methane emissions (CH_4) through waste treatment.

4.1. Carbon Prices in the Carbon Market

Carbon prices in international markets vary depending on regions, regulations, and carbon trading schemes. Carbon prices are currently in the range of USD 30 to USD 50 per ton of CO2 eq, with the average price often used for calculations being around USD 40 per ton of CO2 eq.

4.2 . Calculation of Potential Value of Carbon Trading

Using an average price of USD 40 per ton of CO2 eq, we can calculate the potential value of carbon trading as follows:
Potential Revenue from Carbon Trading = Total GHG Emission Reduction×Carbon Price per Ton of CO2Revenue Potential= 77,826 tonnes of CO2 eq/year× USD 40 per ton of CO2 eq
Potential Revenue = USD 3,113,040 per year
It can be concluded that the potential value of carbon trading for a 1.5 MW capacity PLTBg, with a reduction in emissions of 77,826 tons of CO2 equivalent per year and an average carbon price of USD 40 per ton of CO2 eq, is around USD 3,113,040 per year. This revenue potential shows that PLTBg not only generates electricity from renewable energy but can also generate significant additional revenue through carbon trading schemes, providing financial incentives while supporting the global reduction of greenhouse gas emissions.

5 . Weaknesses of Hybrid Systems and Solutions

Hybrid systems that combine PLTBg and PLN's grid have challenges, such as dependence on organic waste supply, inconsistent water quality, high initial costs, and maintenance challenges (Bartosova et al., 2023; Bayraktar et al., 2023; Hasan et al., 2023; Srivastava et al., 2020; Tencent Research Institute et al., 2021). However, with the right strategy—such as diversification of raw material sources, effective maintenance systems, the integration of energy storage technology, and collaboration with various parties—these weaknesses can be minimized. The result is a more sustainable, efficient system with significant environmental and economic benefits.

5.1. Dependence on Organic Waste Supply

PLTBg relies heavily on the constant availability of organic waste to produce biogas. Fluctuations in the supply of raw materials (whether using agricultural or livestock waste) can decrease biogas production, thereby reducing the efficiency of power plants.

The commonly used ways to deal with this can vary empirically and literally. They are starting from diversifying sources of raw materials (Pal & Tiwari, 2021; Salleh et al., 2020; van der Velden et al., 2022). Ensure that PLTBg has access to various sources of organic waste, including agricultural, livestock, and household waste. This can reduce dependence on one type of raw material. Establish long-term agreements with organic waste suppliers, such as farms or other food processing plants, to ensure a stable supply of raw materials. Build biogas storage facilities to cope with fluctuations in production and provide a stable electricity supply.

5.2. *High Maintenance Rate*

Hybrid systems involving PLTBg and wastewater treatment require complex and continuous maintenance. Biogas systems require regular maintenance to ensure the digester functions appropriately, while anaerobic wastewater treatment systems require periodic maintenance and replacement.

To address this shortage, ensure that the workforce operating the system has received adequate training on how to perform routine maintenance and handle technical issues (Chavalparit & Ongwandee, 2009; Das et al., 2023; Mulu et al., 2021; Principi et al., 2019). Creation of a regular maintenance schedule to ensure all components (digesters, generators, filters, sedimentation tanks, etc.) remain in optimal function. Maintenance management software can help track when equipment needs to be inspected or replaced—proper Preventive and Curative Maintenance Implementation. Invest in high-quality, durable components, particularly for tanks and waste treatment systems, to reduce maintenance frequency.

5.3. High Initial Costs

Another drawback of this hybrid system is that it requires a significant initial investment to build biogas infrastructure, power generators, and water treatment plants. This can hinder small-scale implementation or in areas with limited budgets.

Seeking funding from governments, international institutions, or organizations that support renewable energy projects can be a solution. In many countries, there are subsidy programs for renewable energy and waste management (Bundhoo, 2018; Kit Lim et al., 2019; Mateescu & Dima, 2022; Tonrangklang et al., 2022; Vochozka et al., 2018). Start small and grow gradually so the initial cost is less burdensome. For example, start with small- scale electricity production from biogas before expanding capacity. Partnering with industries that generate large amounts of organic waste can reduce operational costs, as they can share the burden of investment and management.

5. 4. Instability of Energy Supply

PLTBg can generate electricity unsteadily if the biogas supply fluctuates or the digester has a technical glitch. This instability can be a problem for electricity users requiring a constant supply.

The solution to this problem can be to integrate PLTBg with energy storage systems, such as batteries, to stabilize the electricity supply during periods of fluctuations in biogas production (Ohimain, 2015; Prajapati et al., 2021; Putmai et al., 2020; Sarker et al., 2020). We are combining PLTBg with other renewable energy sources, such as solar panels or wind, to provide energy reserves when biogas production is insufficient. Carry out preventive maintenance to prevent system failures and operational disruptions in biogas power plants.

5. 5. Technology and Innovation Challenges

Hybrid technologies like this require continuous innovation to improve efficiency, especially in terms of wastewater treatment from biodigesters and the stability of electricity production from biogas (Alawad & Ibrahim, 2022; Bhatia et al., 2020; Rashama et al., 2019; Testa et al., 2022). Partner with universities or research institutes to continuously develop and improve water and biogas treatment technologies. Conduct periodic technology evaluations to identify opportunities for efficiency improvement. Use data from daily operations to develop the technology further.

4. CONCLUSION

The hybrid system that integrates a biogas power plant (PLTBg) and an on-grid power source presents a promising solution for simultaneously addressing energy generation and sustainable energy management. This system has the potential to generate renewable energy from biogas, reduce greenhouse gas emissions, and treat wastewater for reuse, creating a more sustainable and circular approach to resource management.

However, its implementation has challenges and weaknesses, such as reliance on a stable supply of organic waste, variability in wastewater quality, high initial costs, and the need for regular maintenance. These challenges can be addressed through strategic approaches such as diversifying feedstock, enhancing real-time monitoring systems, leveraging government subsidies, and integrating energy storage for a stable electricity supply.

Moreover, the system offers significant potential in carbon trading, where reducing greenhouse gas emissions—both CO2 and CH_4—can generate additional revenue, enhancing the overall return on investment (ROI). Future research should focus on optimizing biogas production, improving water treatment technologies, integrating with other renewable sources, and exploring carbon trading mechanisms.

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ACKNOWLEDGMENTS

The authors are grateful to Interdisciplinary School of Management & Technology, Institut Teknologi Sepuluh Nopember, Surabaya Indonesia. Furthermore, thankful to the Department of Civil Engineering, Faculty of Engineering and Science, University of Muhammadiyah Bangka Belitung for contributing to the latest and up- todate literature related to this research problem and PT Bangka Asindo Agri (BAA), an Agro-Industrial Company that has a processing Tapioca and Sago Flour located on the West Ring Road, Kenanga, Sungailiat District, BangkaRegency, Bangka Belitung Province.