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Utilization of Biogas from Rice Straw Waste into Electrical Energy to Drive Rice Grain Machines

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Abstract – **Rice plants are a significant contributor to rice production and serve as the primary source of food in Indonesia. With the increase in rice harvests, the issue of rice plant waste, specifically rice straw, becomes prominent. Rice straw waste is frequently burned after the rice harvest, leading to the release of toxic gases and particles into the air, causing air pollution and posing public health problems. Additionally, most grain processing processes still rely on diesel engines fueled by oil. This research aims to harness the potential of biogas from rice straw waste through anaerobic fermentation, utilizing mathematical calculations. Subsequently, an analysis of the potential electrical energy that can be generated is conducted, along with an examination of the costs associated with various components of biogas utilization. The research results show that 4,800,000 kg of rice straw waste per year can produce a biogas potential of 576,000 m³/year. The electrical energy potential of 3,513,600 kWh/year is sufficient to operate a biogas plant as an electrical energy generator for grain processing operations in Koto Laweh Village, running 12 hours every day and producing a total of 240 kWh of electrical energy. This process involves using 960 kg of rice straw waste and an additional 6.5 kg of urea. The estimated cost of components for utilizing rice straw waste reaches Rp. 112,318,925, demonstrating a significant potential for cost savings compared to conventional fuel sources.**

Keywords: anaerobes, rice straw, biogas, electricity

I. INTRODUCTION

The phenomenon of increasing population growth is a common occurrence in every region of Indonesia. In 2020, Indonesia's population was 272.24 million people, and in 2021, it increased to 274.85 million people. With the population growth, there is an impact on energy consumption in Indonesia, which also continues to rise, resulting in the depletion of national energy reserves.[1].

Given the aforementioned challenges, it is imperative to explore and develop new energy sources, particularly renewable energy, in alignment with Presidential Regulation no. 5 of 2006 on the National Energy Policy. Renewable energy is derived from sources such as solar heat, water, wind, geothermal heat, and biomass. Furthermore, renewable energy possesses the advantage of being environmentally friendly, and its abundance in nature is noteworthy. Among the renewable energy sources with substantial potential in Indonesia is biogas [2].

Biogas is a gas produced through anaerobic activity or fermentation of organic materials. The primary components of biogas include methane and carbon dioxide. The raw materials for producing biogas are abundant, with agricultural waste, such as rice plant waste in the form of rice straw, being one of the readily available sources [2].

Rice plants are a key agricultural commodity and serve as the primary food source in Indonesia. West Sumatra Province stands out among the 11 provinces in Indonesia as one of the leading contributors to the country's rice production. According to data from the West Sumatra Central Statistics Agency (BPS), there is an anticipated increase in rice production from 2021 to 2022. The total rice production in 2021 amounted to 1,317,269.29 tons, and it is projected to reach 1,373,532.19 tons in 2022. [4].

Koto Laweh Village, located in West Sumatra Province, is a community where the majority of people derive their livelihoods from the agricultural and plantation sectors. The primary focus of these sectors is rice cultivation, making it the largest agricultural and plantation activity in the village. The upsurge in rice production has consequently led to an increase in grain processing activities within Koto Laweh Village. According to interviews conducted with grain processing workers in Koto Laweh Village, West Sumatra Province, it was revealed that grain processing has been on the rise. In 2020, the grain production reached 2,900 tons, followed by an increase to 3,080 tons in 2021, and a further growth to 3,200 tons in 2022.

In the grain processing process in Koto Laweh Village, rice straw waste is generated, posing environmental challenges. Historically, this straw waste has been disposed of through burning without proper utilization. Another concern is that the rice grain processing still relies on a generator powered by electricity from a diesel generator. Diesel generators utilize fuel oil as their power source to generate electricity. The use of oil fuels contributes to environmental impact and reinforces dependence on fossil fuels. The issues of fuel scarcity and high prices further exacerbate operational challenges in the processing processes.

Numerous research studies related to biogas production from the utilization of rice straw waste have been conducted previously, including a study [9] on the hydrothermal pretreatment of rice straw with alkaline to enhance biogas production. This research employed hydrothermal pretreatment with the addition of NaOH to enhance the production of biogas. [6] This study investigates the impact of substrate composition, specifically a mixture of cow dung and rice straw, on biogas productivity in a semi-continuous reactor. The research employs a reactor comparison approach to determine the influence of substrate composition on biogas productivity when using a combination of rice straw and cow dung in a semi-continuous reactor. On research [5] This research explores the anaerobic co-digestion of a mixture of rice straw and human waste for biogas production. The study utilizes samples and analyzes physicochemical characteristics to optimize biogas production from human waste and determine the optimal amount of rice straw that should be added.. On research [2] The Village Potential Program focuses on the processing of rice straw waste. The utilization of this pocketbook for rice straw waste processing is based on observations and assessments of the potential for straw processing. On research [3] This study focuses on biomass energy planning, specifically utilizing rice waste as an alternative fuel for electricity generation.

The research employs literature studies and field surveys to gather information about rice straw, biomass, biogas, and the biogas formation process. Building upon previous studies, the research delves into the various applications of rice straw, with a specific emphasis on exploring optimal biogas production through the addition of urea. The inclusion of urea aims to optimize biogas production by enhancing and balancing the C/N ratio. Maintaining an optimal C/N ratio is crucial for an efficient biogas production process; if the ratio is too high or too low, it may hinder the optimal production of biogas. Given that rice straw waste often has a high C ratio, the addition of urea becomes essential to balance the C/N ratio, as urea contains a substantial nitrogen content, approximately 46% per kilogram. [22].

The produced biogas will undergo conversion into electrical energy. For the calculations of biogas production and the potential for electrical energy, please refer to research [3]. The objective is to replace diesel generators with biogas generators in grain processing machines. Additionally, this study will conduct a cost analysis for purchasing biogas production components and compare the cost savings achieved by utilizing a biogas generator instead of a diesel generator. Through the application of the anaerobic fermentation method and mathematical calculations, this research is specifically focused on testing biogas potential, electrical energy generation, and analyzing the costs associated with biogas production components. It also involves comparing the expenses related to using a diesel generator versus a biogas generator based on the available biogas potential. It's important to note that this research has not yet progressed to direct implementation in existing case studies.

II. METHODS AND RESEARCH

A. Data Collection Process and Process Parameter Collection.

1. Data Collection

The data utilized in this research is primarily sourced from direct observations at the grain processing facility in Koto Laweh Village. The obtained data includes information on rice grain production volume, specifications of the rice grain generator machine, and operational costs associated with the grain processing machine generator. The detailed data is as follows:

a. Rice Grain Production Data

Rice grain production refers to the quantity of grains yielded from rice plants following the harvest process. Grains are the culmination of the growth of rice plants and serve as the primary raw material in rice production. The grain production process involves several stages, beginning with planting rice seeds, caring for the plants, and concluding with the harvesting phase. The data regarding grain production in the grain processing facility in Koto Laweh Village is as follows:

Table 1. Data on the amount of rice grain production from Heller Padi in Koto Laweh Village

No	Year	Amount of Rice Grain (Tons)
1	2020	2.900
2	2021	3.080
3	2022	3.200

According to research references [21], as shown in Table 1, it is indicated that for every 1 kg of rice grain produced, rice plants generate between 1 and 1.5 kg of rice straw waste. Consequently, the total output of rice straw waste is projected to be 4,350 tons in 2020, 4,620 tons in 2021, and 4,800 tons in 2022.

b. Rice Grain Machine Power Plant Specification Data

A rice grain machine generator is designed to generate electrical energy, with the produced electricity being distributed to the motor responsible for driving the grain processing machine. The specifications for the generator are as follows:

Table 2. Specifications for Rice Grain Processing Machines

No	Specification	Information

1	Brand	Yanmar
2	Engine Power	23HP / 18,64 KW
4	Engine rpm	2200 RPM
6	Machine Steps	4 Steps
8	Fuel tank capacity	21.5 L
9	Oil Capacity	6 L
10	Heavy	205 Kg

In the grain processing procedure, a generator engine serves as the energy source to drive the grain processing machine. Specifically, the Yanmar TS230H-di generator engine is employed in this process to produce mechanical energy. The sequence initiates with the conversion of electrical energy from fuel oil by the generator. Subsequently, the motor on the generator transforms it into mechanical energy. This mechanical energy, in turn, propels the rotation of the shaft and wheels, acting as the driving force for the grain processing machines through a belting system, facilitating distribution.

c. Data on Fuel Costs for Power Plants for Grain Processing Machines

Table 3. Average Monthly Operating Costs for Rice Grain Processing Machine Power Plants.

No	Parameter	Units (Liter)	Price (Rp)
1	July	1.250	Rp. 12.500.000
2	August	1.040	Rp. 10.400.000
3	September	1.210	Rp. 12.100.000

In Table 3, the data obtained from Heller grain processors in Koto Laweh Village reveals the cost of fuel for powering the grain processing machines. The grain processing factory in Koto Laweh Village operates daily, from 06:00 to 18:00, processing an average of 8 tons of grain per day. The machinery needs to be operational for 12 hours each day. In July 2022, the fuel consumption was 1,250 liters at a cost of Rp. 12,500,000. In August, 1,040 liters were used at a cost of Rp. 10,400,000, and in September, the fuel usage was 1,210 liters at a cost of Rp. 12,100,000.

2. Process Parameters

Process parameters are essential values that function as references and input materials in the process of converting rice straw waste into biogas using mathematical calculations. Throughout the mathematical calculations involved in the various stages of biogas production, specific data is required concerning the characteristics of the raw material, which in this case is rice straw waste. The data pertaining to the characteristics of rice straw waste raw materials are as follows [3]. :

Table 4 Characteristics of Several Types of Raw Materials Digested in Biogas Production.

Raw material	C/N Ratio	VS(%)of DM / TS	Biogas Yield (m³/kg of VS)
Straw	60 – 100	80-90	0,15 – 0,35
Garden Wastes	100-150	90	0,20 – 0,50
Fruit Wastes	35	75	0,25 – 0,50

In Table 4, it is noted that the C/N ratio of rice straw waste falls within the range of 60-100%, the TS (Total Solids) value is between 80-90%, and the biogas yield from rice straw waste is estimated to be in the range of 0.15-0.35 m³/kg.

B. Calculation of Biogas Production

In the biogas production process, several factors play a crucial role in influencing the formation of biogas. These factors include, but are not limited to:

1. C/N Ratio

The C/N ratio is crucial because, in principle, methane gas (biogas) contains the elements carbon (C) and nitrogen (N). Therefore, any organic materials containing C/N elements can be utilized as raw materials for biogas production. The ratio between C/N elements significantly influences the formation of biogas. Empirically, the most preferred C/N ratio falls within the range of 10 – 30. If the C/N ratio is too high, biogas production will not be optimal, and if it is too low, ammonia will form, hindering the decomposition process from running optimally.

Rice straw has a C/N ratio of 60, with carbon (C) at 18% and nitrogen (N) at 0.30% [3]. To calculate the values for the C ratio, N ratio, and C/N ratio for rice straw waste, the following equations (Equations 1, 2, and 3) are utilized:

$$Ratio\ C\ = Amount\ of\ raw\ materials X\ \%C \quad (1)$$

$$Ratio\ N\ = Amount\ of\ raw\ materials\ X\ \%N \quad (2)$$

$$Ratio\ C/N = \frac{\text{Rasio C}}{Rasio\ N} \quad (3)$$

To optimize the C/N ratio value of rice straw waste during the biogas production stage, it is necessary to add urea to address the low nitrogen (N) ratio in rice straw waste. Urea contains a nitrogen content of 46% per kilogram. [22]. By adding urea in proportion to the amount of rice straw waste to be processed into biogas, the biogas production stages will be more optimal.

2. Solids Content / Total Solids (TS)

In the biogas production process, the solids content (TS), also known as dry matter (DM), represents the quantity of solids present in organic waste during the digestion process. This measurement indicates the rate of decomposition or breakdown of solid organic waste materials. Volatile solids (VS) constitute the solid portion (TS) that transforms into the gas phase during the acidification and methanogenesis stages, as observed in the fermentation process of organic waste. VS serves as an initial indicator of the formation of methane gas (biogas) [3].

Referring to Table 4, the assumed total solid content (TS%) value of rice straw waste is 80%, and it is assumed that 0.15 m³ of biogas can be produced from 1 kg of straw.

To determine the actual total TS value of rice straw waste, Equation 4 is utilized.

$$Total\ value\ (TS) = TS(\%)\ \text{X}\ Amount\ of\ Rice\ Straw \quad (4)$$

To calculate the methane gas produced in the biogas production process from rice straw waste, Equation 5 is employed.

$$Biogas = Total\ value\ TS\ \text{X}\ biogas\ results\ 1\ kg \quad (5)$$

C. Electrical Energy Calculations

The biogas potential derived from rice straw waste can be harnessed to generate electrical energy. Biogas power plants provide an effective means to utilize organic waste and produce electrical energy. To assess the potential for electrical energy from biogas, one can refer to the data on the ratio of biogas energy to commercial energy, as presented in the following table:

Table 4. Energy Comparability Value

No	Fuel	Energy Value	Biogas (m^3)	Solar (l)	Electricity (Kwh)
1	1 m^3 Biogas	22,10 MJ	1,00	0,61	6,10
2	1 liter of Diesel	36,00 MJ	1,63	0,93	10,00
3	1 Kwh Electricity	0,16	0,16	1,20	1,00

According to Table 4, it is established that 1 m^3 of biogas is equivalent to 6.10 kWh of electrical energy. Therefore, the potential electrical energy produced from the biogas generated by rice straw waste can be calculated based on this energy proportionality value. This potential biogas can be converted into electrical energy using a biogas generator. A biogas generator is a device that utilizes biogas as fuel to generate electrical energy. Electrical energy is typically measured in watts and kilowatts, often expressed in terms of power (electrical power produced within a specific time) or energy (total electric power produced within a specific time), measured in kilowatts or kWh. Through the generation of electrical energy from a biogas generator, calculations can be performed to determine the amount of electrical energy produced, the consumption of biogas fuel, and the operational duration of the biogas generator using mathematical calculations. The mathematical calculations conducted are as follows:

To calculate the electrical energy produced from a biogas generator, you can use equations 6, 7, and 8. As follows:

$$Electrical\ energy = Operating\ Time\ \text{XGenerator Power} \quad (6)$$

Electrical energy : Generated Output Energy (kWh)
Operating Time : Time Used (Hour)
Generator Power : GeneratorSpecificationPower(kW)

Calculation of the amount of biogas used can be calculated using the equation 7 :

$$total\ biogas = \frac{Operating\ Time \times biogas\ fuel}{} \quad (7)$$

Total Biogas : Total Biogas Generator Fuel Consumption (m^3)
Operating Time : Time Spent (Hours)
Fuel Consumption : Total Fuel Consumption (m^3)

To determine the daily operational duration of the generator, you can utilize Equation 8:

$$Operating\ Time = \frac{Total\ Biogas\ Potential}{Fuel\ Consumption} \quad (8)$$

Operating Time : Time Spent (Hours)
Amount of Biogas : Amount of Potential Biogas Results Per Day from Rice Straw Waste (m^3)
Material Consumption Burn : Total Generator Fuel Consumption (m^3)

D. Calculation of Biogas Utilization Costs and Fuel Comparison

In harnessing the biogas potential from rice straw waste, it is essential to calculate the cost of utilizing biogas to determine the capital components involved in implementing biogas using rice straw waste. In this study, researchers focused solely on the cost analysis of components for utilizing biogas from rice straw waste. For details on component costs and types of components used, please refer to the research. [1]. The fuel comparison involves utilizing data on the quantity of fuel used for a diesel generator power plant in grain processing machines, compared with a biogas generator power plant following the utilization of biogas potential from rice straw waste.

III. RESULTS AND DISCUSSION

A. Rice Straw Biogas Potential

With data on the amount of rice straw in Koto Laweh Village in 2022, as shown in Table 1, amounting to 3,840,000 kg/year and 10,520 kg/day, the biogas potential is derived from the C/N ratio, TS value, and the quantity of urea added, as follows:

1. C/N Ratio

Table 5. Rice Straw C/N Ratio

No	Amount of Waste	Ratio C (%)	Ratio N (%)	C/N
1	4.800.000 kg/year	864.000	14.400	60
2	13.150 kg/day	2.367	39,45	60

According to Table 5, it is observed that the C/N ratio of rice straw waste indicates a total C/N ratio of 60. This value is suboptimal for the biogas production process..

2. Additional Urea

Given the suboptimal C/N ratio of rice straw waste in the biogas production process, a total additional urea is calculated as a supplement to the mixture of rice straw waste to be used in the biogas production stage, as detailed in Table 6 below:

Table 6. Urea Addition for C/N Ratio

No	Amount of Waste	Urea Amount (kg)	C/N
1	4.800.000 kg/year	32.000	29,67
2	13.150 kg/day	86	29,95

In Table 6, the quantities of urea added to rice straw waste destined for biogas processing are detailed. With a waste amount of 4,800,000 kg/year, an additional 32,000 kg of urea is required. Similarly, for a daily waste amount of 13,150 kg, an additional 86 kg of urea is needed. These findings suggest that the biogas production process will yield optimal results.

3. Solids Value (TS)

The results of the Total Solids (TS) values for rice straw waste and the additional urea can be observed in Table 6 below:

Table 7. TS Value of Rice Straw with Urea Addition

No	Amount of Waste	Urea Amount	TS value
1	3.840.000 kg/year	32.000 kg	3.093.600 kg
2	10.520 kg/day	86 kg	8.472 kg

In Table 7, the Total Solids (TS) values are outlined. For rice straw waste totaling 4,800,000 kg/year, the addition of 32,000 kg of urea yields a TS value of 3,840,000 kg/year. Similarly, for daily rice straw waste of 13,150 kg, along with the addition of 86 kg of urea, a TS value of 10,520 kg/year is achieved.

4. Biogas Production

The biogas potential from rice straw waste in Koto Laweh Village is obtained as follows:

Table 8. Biogas Production Results

No	TS value	Biogas Results
1	3.840.000 kg/year	576.000 m³/ year
2	10.520 kg/ day	1.578 m³/day

Based on the calculations of biogas potential derived from rice straw waste in Koto Laweh Village, it is determined that rice straw waste has the capacity to generate a biogas potential of 576,000 m³/year and 1,578 m³/day.

B. Electrical Energy Potential

The potential biogas derived from rice straw waste can be converted into electrical energy. The production of electrical energy from biogas generated from straw waste can be illustrated as follows:

Table 9. Results of Electrical Energy Potential

No	Biogas	Electrical energy
1	576.000 m³/year	3.513.600 Kwh/year
2	1.578 m³/day	9.625,8 Kwh/day

In Table 9, the results reveal that the potential electrical energy derived from the biogas production of 576,000 m³/year can yield 3,513,600 kWh/year. Furthermore, with a daily biogas production of 1,578 m³, it has the capacity to produce electrical energy amounting to 9,625.8 kWh/day.

C. Use of Rice Straw Waste Biogas

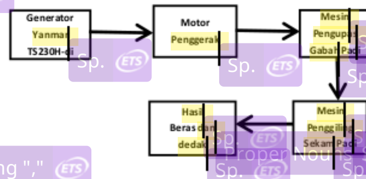

Figure 1. Rice Grain Processing Scheme

In Figure 1, it is evident that in the grain processing process, the generation of electrical energy to power the rice grain machine motor still relies on a diesel generator using fuel oil. However, the goal of this research is to substitute the role of diesel generators with biogas generators.

Adjusting the power requirement of the existing grain processing machine from a diesel generator, which is 18.54 kW, this research will utilize the Jet Power NG-28 biogas generator as the electricity generator. The specifications are detailed in Table 10 below:

Table 10. NG-28 Biogas Generator Specifications

No	Specification	Information
1	Manufacture	Jet Power (NG-28)
2	Output Power	25 KVA / 20 KW
3	Fuel Consumption	12 m³/h
4	Generator Prices	Rp. 61.833.400

In Table 7, the specifications of the Jet Power NG-28 biogas generator are examined in relation to the power required for operating the grain processing machine. The potential biogas produced from rice straw waste is deemed adequate to meet both generator fuel consumption and electrical energy needs.

The total electrical energy produced from the Jet Power NG-28 biogas generator can be calculated using Equation 6. Similarly, the total consumption of biogas can be determined using Equation 7, and to calculate the amount of rice straw used, Equation 8 is applied, as detailed below:

$$Electrical\ energy = 12\ jam \times 20kW = 240\ kWh$$

$$Total\ Biogas = 12m^3 \times 12\ jam\ = 144\ m^3$$

$$Total\ Rice\ Straw = \frac{144\ m^3}{0{,}15m^3}\ = 960\ Kg$$

By employing the Jet Power NG-28 biogas generator as an electrical energy source to drive the grain processing machine motor, the operational hours of the Koto Laweh Village rice factory are determined to be 12 hours per day. The total electrical energy generated from the Jet Power NG-28 biogas generator is 240 kWh. Additionally, it has the capability to operate a rice grain processing machine with a total biogas consumption of 144 m³, along with a total requirement for rice straw of 960 kg and an additional urea mixture of 6.5 kg, resulting in a total C/N content of 29.43 in a day.

Hence, the comparison of fuel consumption between the Yanmar TS230H-di diesel generator and the Jet Power NG-28 biogas generator, both serving as electrical energy generators to drive the rice grain processing motor, yielded the following results:

Table 11. Comparison of Fuel Consumption.

No	Parameter	Yanmar TS230H-di	Jet Power NG-28
1	12 hour fuel	61,74 L Solar	144 m³ Biogas

According to Table 11, an analysis of fuel consumption between the Yanmar TS230H-di and the Jet Power NG-28 over a 12-hour period reveals a significant difference. The Yanmar TS230H-di consumes 61.74 liters of diesel per day, whereas the Jet Power NG-28 utilizes 144 m³ of biogas per day. This comparison underscores the substantial potential for fuel savings with the transition to biogas.

D. Calculation of Costs for Utilizing Rice Straw Waste Biogas

From table 11. Analysis of fuel consumption between the Yanmar TS230H-di and the Jet Power NG-28 over a period of 12 hours shows that there is a significant difference. The Yanmar TS230H-di uses 61.74 liters of diesel/day, while the Jet Power NG-28 uses 144m³/day of biogas. This comparison reflects the potential for large fuel savings by switching to biogas:

Table 12. Component Cost Estimation

No	Equipment	Price
1	Grinding	Rp. 21.194.000
2	Mixing	Rp. 7.950.000
3	Cenrifugal Pump	Rp. 6.650.000
4	Anaerobic Digester	Rp. 14.691.525
5	Generator Biogas Jet Power NG-33	Rp. 61.833.400
6	**Total**	**Rp. 112.318.925**

In Table 12, with an initial capital of Rp. 112,318,925, processing rice grain can harness the potential of biogas as an electricity generator and utilize unused straw waste. To economize on fuel for power plants that were previously reliant on diesel generators, the rice mill heller can leverage the biogas potential from rice straw waste to generate electrical energy using the biogas generator. Several equipment components needed for the biogas production stages are detailed in Table 12. It's important to note that in this research, we focus solely on determining the components to be used in the biogas production process, excluding the costs of capital return and the design of the biogas production process from rice straw waste.

Assumptions regarding biogas stability include the availability of organic raw materials, the efficiency of the anaerobic fermentation process, and the composition of the biogas according to standards with methane as the main component. Other crucial factors such as practical aspects in biogas utilization include various important elements, ranging from the availability and accessibility of organic raw materials to the efficiency of biogas production technology, system maintenance and upkeep, as well as infrastructure that supports biogas use. Energy efficiency in converting raw materials into biogas, management of output in the form of waste and residual solids, and utilization of by-products are also key considerations. In addition, economic aspects such as investment costs, investment recovery, and regulatory support that supports sustainability have a significant impact. Community involvement in acceptance and support of biogas technology is also a key factor in its successful implementation. Understanding and managing all these practical aspects is necessary to ensure the success, sustainability and maximum benefits of implementing biogas technology in real-world scenarios.

IV. CONCLUSION

The biogas potential from rice straw waste in Koto Laweh Village reaches 576,000 m³ per year and 10,520 m³ per day, indicating a significant potential as an energy source. The conversion of biogas to electrical energy can yield 3,513,600 kWh per year and 9,625.8 kWh per day, as shown in Table 9. Replacing the diesel generator with a biogas generator in rice grain processing (Figure 1) has the potential to reduce fuel consumption and greenhouse gas emissions, with a comparison of 61.74 liters of fuel and 144 m³ of biogas.

The estimated cost of components in utilizing biogas reaches Rp. 112,318,925. Although this is only a preliminary estimate, the utilization of biogas potential is considered economically viable. Replacing diesel generators with biogas generators is expected to enhance energy efficiency, reduce environmental impact, and sustainably utilize rice straw waste.

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