Sustainable Energy Integration: Solar and Biogas Solutions for a Disability Center in Rural Gianyar, Bali

Luh Putu Deswinta Dharmariani[1], Muhammad Fachmi Kurniawan[2] and Muhammad Iqbal Sugiharto[3]

[1] Faculty of Mathematics and Natural Sciences, Universitas Udayana, 80361 Bali, Indonesia
[2, 3] Society of Renewable Energy Indonesia, 12160 Jakarta, Indonesia
deswintadhr@gmail.com, fachmi@sre.co.id, iqbal@sre.co.id

Abstract. This paper explores the implementation and impact of a sustainable energy integration program at Yayasan Widya Guna, a disability center in Rural Gianyar, Bali. The project aimed to address the center's high energy demands, particularly for Aquatherapy, by utilizing renewable energy sources. It involved integrating a biogas system with a capacity of 3 m³ and a solar panel system with a capacity of 3.3 kWp and 10 kWh of energy storage, significantly reducing electricity costs by approximately Rp6,960,000 per month. The biogas system uses local organic waste, while the solar panels have collectively decreased the center's reliance on conventional electricity, achieving an energy efficiency rate of 13.2 kWh/day for solar panels and 3 m³ for biogas. The biogas also substitutes 3 kg of LPG (Liquefied Petroleum Gas) for cooking and supports the operational needs of a café run by students with special needs. Overall, the project reduces carbon emissions by 9 tons CO_2eq/year, significantly contributing to environmental sustainability goals. Challenges included initial community resistance, ongoing maintenance needs, and securing funding for system upkeep and expansion. These were addressed through technical training for local staff and volunteers, community engagement to raise awareness, regular maintenance schedules, and sustainable funding strategies. This study highlights the potential of renewable energy integration in fostering sustainable development. The Yayasan Widya Guna model serves as a replicable example for other rural communities, demonstrating the feasibility and benefits of renewable energy solutions to meet local needs and promote environmental conservation and community development.

Keywords: Renewable, Rural, Sustainable

1 Introduction

The transition to renewable energy sources is becoming an increasingly serious worldwide issue, particularly in developing countries such as Indonesia. Population growth has led to an increase in energy demand [1]. The increasing demand for energy, combined with reliance on fossil fuels, contributes to greenhouse gas emissions and climate change affecting global ecosystems [2,3]. As attested in the National Energy General Plan (RUEN), to reduce negative environmental impacts and support climate change mitigation efforts, the Indonesian government has set a target to increase the share of renewable energy in the national energy mix to 23% by 2025 [4].

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M. Musyarofah et al. (eds.), *Proceedings of the 5th Borneo International Conference (BICAME 2024): Symposium on Digital Innovation, Sustainable Design and Planning (DSP)*, Advances in Social Science, Education and Humanities Research 882,
https://doi.org/10.2991/978-2-38476-329-0_6

Sustainable energy plays a crucial role in sustainable rural development. Rural areas' dependence on conventional energy is a heavy economic burden. The adoption and integration of renewable energy technologies, such as solar panels and biogas systems, offer solutions that have the potential to reduce energy costs, improve energy supply stability, and support local economic growth [5,6]. Furthermore, renewable energy can help reduce carbon emissions and air pollution, which is important for preserving a healthy environment and enhancing people's quality of lives, especially people with disabilities who often face challenges in accessing basic services [7,8].

Indonesia's specific challenges in renewable energy development involve various aspects. The first is inadequate infrastructure. Indonesia's archipelago implies isolated places still lack access to the electricity grid, making renewable energy projects ineffective. Second, Indonesia's inconsistent energy policies inhibit investment in the renewable energy sector. Furthermore, obscure and complex regulations also delay the process of licensing and development of renewable energy projects. Another challenge for developing countries like Indonesia is the high initial investment in renewable energy technologies [9,10].

Furthermore, infrastructure, policy and funding challenges, it is also necessary to increase public awareness and skills on the relevance of renewable energy and its environmental impact. Public awareness campaigns and training in the management and maintenance of renewable energy technology systems are required for building support from the community. With a better understanding of the benefits of renewable energy, people will certainly support the energy transition program and be actively involved in the use of clean energy. Although Indonesia faces significant hurdles in developing renewable energy, it also has a huge opportunity. That potential opportunity is the abundance of natural resources. The use of renewable energy sources provides an environmentally favorable option. In Indonesia, especially in Gianyar, Bali, there is great potential to develop renewable energy as an inclusive and sustainable energy solution.

Yayasan Widya Guna, a disability center in rural Gianyar, Bali is a place of care and training for people with disabilities and orphans. One of the foundation's significant electricity needs is for the operation of therapy systems, especially aquatherapy. The foundation's significant need for electricity to support daily operations necessitates the rapid development of more efficient and sustainable energy solutions. Yayasan Widya Guna provides an opportunity to address this challenge by leveraging the accessible potential of solar and biogas energy. Solar panels were chosen for the capacity to generate clean energy from Bali's abundant sunlight, while the biogas system utilizes local organic waste, which not only promotes sustainability but also provides an efficient waste management solution [11,12,13].

This research aims to explore the potential and implementation of sustainable energy integration in Yayasan Widya Guna through the utilization of solar panels and biogas. The study also aims to provide insights that can be replicated by other rural communities, especially in areas with similar characteristics. Therefore, the project not only improved operational efficiency, but also encourages a culture of sustainability in line with wider environmental conservation and community development goals.

2 Literature Review

2.1 Renewable Energy in Rural Areas

Renewable energy projects in rural areas of Indonesia have shown significant potential in providing sustainable and reliable energy solutions, reducing environmental impact, and improving the quality of life for rural populations. Various studies have highlighted the critical role of renewable energy in supporting sustainable development in rural Indonesian settings.

Pusparini et al. (2021) examined several renewable energy initiatives implemented in rural Indonesia, emphasizing the importance of solar and micro-hydro energy in providing off-grid solutions for remote communities. Their findings indicated significant improvements in energy access for rural households, leading to economic benefits such as increased productivity and income generation. Additionally, the study noted enhancements in social aspects, such as better educational opportunities due to improved lighting and energy access in schools and homes.

Utami and Saputra (2020) explored the deployment of solar photovoltaic (PV) systems in several rural Indonesian villages. Their research found that solar PV systems effectively met the energy needs of these communities, particularly in areas without access to the national grid. The introduction of solar PV systems reduced reliance on traditional biomass and kerosene, resulting in decreased indoor air pollution and improved health outcomes. Furthermore, the availability of reliable solar power supported small businesses, enabling extended operational hours and enhanced economic activities.

The Biogas Rumah (BIRU) program, initiated by the Indonesian government, has been a significant success in promoting biogas technology in rural areas. Dewi et al. (2020) detailed the impact of the BIRU program, which led to substantial reductions in firewood consumption and indoor air pollution. The study found that biogas plants provided a clean and efficient energy source for cooking and lighting, improving the overall quality of life for rural households. The program also created job opportunities and fostered community participation in sustainable practices.

These studies collectively indicate the feasibility and benefits of renewable energy projects in rural Indonesia. They demonstrate how such projects can improve energy access, enhance economic conditions, and promote environmental health, contributing to the overall sustainable development of rural areas.

2.2 Biogas and Solar Energy Integration

The integration of biogas and solar energy systems is an emerging area of interest in the field of renewable energy. This approach offers complementary benefits and enhances the overall sustainability of energy solutions in rural areas. Combined systems leverage the advantages of both technologies to provide a more reliable and efficient energy supply.

Lund (2007) discussed the potential of hybrid renewable energy systems, highlighting that combining solar PV and biogas systems can address the intermittent nature of solar energy. Biogas systems can provide a continuous energy supply, especially during non-sunny periods, ensuring a stable and reliable energy source for rural communities. This integration maximizes energy efficiency and sustainability, making it a viable solution for off-grid rural areas.

In Indonesia, recent studies have demonstrated the benefits of integrating biogas and solar energy systems. Nugroho et al. (2021) examined the performance of integrated biogas and solar PV systems in rural Indonesian households. Their study found that hybrid systems significantly improved energy security by reducing dependency on imported fossil fuels. The integration of these systems also enhanced the overall efficiency and reliability of the energy supply, particularly in remote, off-grid areas. The study highlighted that such integrated systems could meet the diverse energy needs of rural households, including electricity for lighting and appliances, as well as clean cooking solutions.

Santoso et al. (2022) conducted a case study on the integration of biogas and solar PV systems in rural Indonesian villages. Their research demonstrated that the hybrid system could effectively meet the energy demands of rural households more efficiently than individual systems alone. The study emphasized the importance of community involvement and the utilization of local resources in the success of these projects. By engaging the local community in the planning and implementation phases, the projects gained greater acceptance and sustainability. The integrated systems provided a reliable energy supply for household needs and supported local economic activities, contributing to improved living standards and environmental benefits.

These studies underscore the potential benefits of integrating biogas and solar energy systems. Such integration can enhance energy reliability, efficiency, and sustainability in rural Indonesian areas. The combination of these technologies can address the unique energy challenges faced by rural communities, offering a replicable model for sustainable development.

2.3 Educational and Social Impact of Renewable Energy Projects

The implementation of renewable energy projects globally has triggered intensive discussions regarding their widespread impacts, not only on the environment but also on the social and educational aspects of society. In recent years, renewable energy projects and research efforts that reflect sustainable energy sources have attracted attention. This literature highlights insights into the impact of renewable energy projects in the educational and social spheres of society.

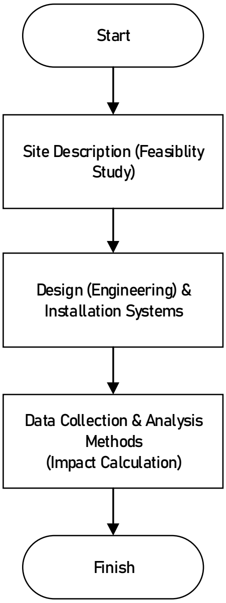
In case studies conducted by Muksin et al. (2023) and Saleh et al. (2023), the impact of a wind power project in Sulawesi was found. The existence of renewable energy projects also contributes positively to the improvement of skills and knowledge related to wind power technicalities. In addition, the project also absorbed local labor and increased community income. Economic growth also occurs because the PLTB increases the availability of additional electrical energy that supports the stability of electricity flow in the Sidenreng Rappang Regency area.

Furthermore, in the energy transition process, Daoudi (2024) emphasizes that renewable energy education plays an important role. Its role is not only in disseminating knowledge but as a catalyst for raising awareness among the wider community about the importance of renewable energy. In the research of Moridu et al. (2023), environmental sustainability education programs also found the important role of education in the clean energy transition. This program combines environmental education and community empowerment, which includes tree planting, recycling centers, and compost programs. Through this program, there is a change in behavior in the use of disposable plastics and waste management.

In overall terms, these studies show that there is great potential to improve education, empower communities, and increase energy independence. By integrating renewable energy education into renewable energy projects and encouraging community participation, these projects can be a powerful tool for promoting sustainable development.

3 Methodology

The methodology for the Sustainable Energy Integration project at Yayasan Widya Guna focuses on the systematic design and implementation of renewable energy systems and the evaluation of their impact. This comprehensive approach aims to provide a replicable model for integrating renewable energy sources in rural settings.



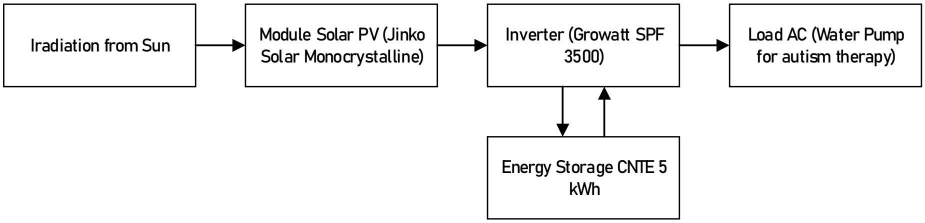
Overview of the key aspects related to site description, design engineering, installation systems, and data collection & analysis methods, site description location and context: understanding the geographical, cultural, and socio-economic context of the site. physical characteristics, documenting topography, soil conditions, vegetation, existing structures, and climate. infrastructure, assessing access to utilities, transportation, and other essential services.

Design engineering involves creating detailed plans and specifications for the project. Key steps include conceptual design, developing initial design concepts based on site analysis and project requirements. Detailed design, creating detailed drawings and specifications, including structural, electrical, and mechanical systems. Installation System

The installation system covers the practical implementation of the design. This includes, planning, developing a detailed installation plan, including timelines, resources, and logistics. Procurement, sourcing materials and equipment needed for the project. Construction, executing the installation according to the design specifications, ensuring quality control and safety.

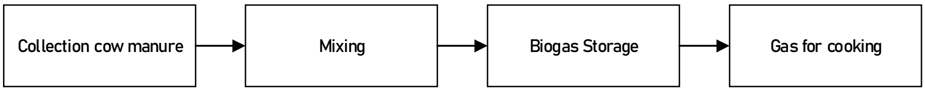
Data collection & analysis is obtained from real-time online monitoring features provided by the Growatt inverter. The data is analyzed to assess the impact of savings and the conversion of carbon reduction resulting from the use of solar power plants (PLTS). The value of biogas is determined by the amount of cow manure collected at the Wiguna Foundation farm, which can produce methane gas for cooking.

Blok Diagram Solar PV Hybrid Off-Grid System



The working principle of the solar power plant (PLTS) is that solar radiation at the Wiguna Foundation is captured by solar panel modules. The solar panel modules convert solar energy into DC (Direct Current) electricity, which then goes to an inverter to convert the DC voltage to AC (Alternating Current) so it can be used for the therapy pool pump. The challenge of PLTS is intermittency, so additional backup energy is added to overcome energy shortages when the PV modules cannot convert solar energy into electricity.

Blok Diagram Biogas System



Collection, cow manure is collected from the farm. Mixing, the collected manure is mixed with water to create a slurry. Anaerobic digestion, the slurry is fed into an anaerobic digester, where bacteria break down the organic matter in the absence of oxygen, producing biogas. Biogas storage, the produced biogas is collected and stored in a gas holder. Utilization, the stored biogas is used for cooking.

3.1 Site Description

Yayasan Widya Guna is a disability center located in Bedulu Village, Gianyar, Bali. Founded in 2006 by Ketut Sadia and Gill Rijnenberg, the foundation provides support and education for children with special needs and orphans. The center serves 98 students, with 43 having special needs. The facilities include classrooms, therapy rooms, aquatherapy pools, play areas, and a café and kitchen managed by students with special needs. These facilities are designed to meet the needs of the children, fostering growth, self-reliance, and future responsibility [7].

The center's high energy demand, estimated at around 7,000 kWh per month, encompasses lighting, therapy equipment operation, aquatherapy pools, and kitchen and café functions. These energy needs significantly impact operational costs, necessitating more sustainable solutions [14]. The goal of this project is to reduce reliance on conventional energy sources and lower operational expenses through renewable energy integration.

3.2 Design and Installation of Systems

The project involves designing and implementing integrated renewable energy systems, including a biogas system and a solar panel system, to meet the center's energy needs efficiently.

Biogas System Design and Installation:

The biogas system is designed to process local organic waste, such as food scraps and agricultural residues, into a clean energy source for cooking. With a capacity of 3 m^3, the system reduces the reliance on conventional LPG cylinders [16]. Key components of the biogas system include:

a. Digester: The digester is a closed chamber where organic waste is decomposed anaerobically to produce biogas. It was constructed using local materials to ensure cost-effectiveness and sustainability.
b. Gas Storage: The biogas is collected and stored in a flexible storage tank, designed to accommodate daily fluctuations in gas production and demand.
c. Piping System: A network of pipes connects the gas storage to the kitchen and café, allowing for direct usage in cooking and other applications.
d. Cooking Stoves: The kitchen was equipped with specially adapted stoves designed to use biogas efficiently and safely.

The installation involved securing the solar panels to the roof and connecting them to the inverter and battery storage system. Electrical wiring was integrated into the center's existing power infrastructure, ensuring seamless operation. Local staff and volunteers were trained in basic maintenance tasks to ensure long-term system reliability [14].

Ensuring system reliability and maintenance posed a challenge due to the lack of technical expertise. This was addressed by implementing a training program for local staff and volunteers, equipping them with the skills needed for routine maintenance and troubleshooting. A regular maintenance schedule was established to ensure optimal system performance [18].

3.3 Data Collection and Analysis Methods

The evaluation of the project's impact was conducted using a comprehensive data collection and analysis framework, focusing on energy consumption, cost savings, carbon emissions reduction, and community development.

Challenges and Solutions:

Energy meters were strategically installed throughout the facility to monitor electricity usage from the grid and solar panel system, as well as biogas production and utilization [18].

a. Pre-Implementation Baseline: To establish a baseline, data was collected for three months before the renewable energy systems were installed. This included tracking electricity consumption for lighting, therapy equipment, and kitchen appliances, as well as LPG usage.
b. Post-Implementation Monitoring: Following installation, energy consumption data was continuously collected over 12 months. This involved monitoring the electricity generated by the solar panels, biogas production, and any changes in grid electricity consumption and LPG usage.

Analysis:

a. Energy Reduction Calculation: The analysis compared pre- and post-installation energy usage data to quantify reductions in grid electricity consumption and LPG usage. The efficiency rates of the solar panels (13.2 kWh/day) and biogas system (3 m^3/day) were calculated to assess performance. The analysis revealed significant energy reductions, highlighting the effectiveness of the integrated systems in meeting the center's energy needs sustainably.
b. Usage Patterns: Detailed analysis of daily and seasonal usage patterns helped identify peak demand periods and optimize system performance. This data informed adjustments to system operations to maximize efficiency and reliability [14].

Cost Savings Calculation:

Financial records were reviewed to document electricity and LPG costs before and after the implementation of the renewable energy systems.

a. Savings Calculation: The cost savings were calculated by comparing the center's pre-implementation energy expenses with post-implementation costs. The analysis demonstrated significant financial benefits, with electricity costs reduced by approximately Rp6,960,000 per month. This economic impact underscored the value of renewable energy integration [21].
b. Return on Investment (ROI): An ROI analysis was conducted to evaluate the project's financial viability, considering the initial capital investment, operational savings, and projected system lifespan. The results indicated a favorable ROI, supporting the economic case for renewable energy integration.

Carbon Emissions Reduction Assessment:

To assess environmental benefits, emissions data was used to estimate the reduction in carbon emissions resulting from decreased reliance on fossil fuels and increased use of renewable energy sources.

Emissions Reduction Calculation: Standard conversion factors were applied to calculate the decrease in carbon emissions from reduced grid electricity consumption and LPG usage. The project achieved an annual reduction of 9 tons CO_2eq/year, demonstrating significant environmental benefits. This reduction aligns with the center's sustainability goals and contributes to broader efforts to combat climate change [18].

Community Feedback and Impact Assessment:
Qualitative data was gathered through surveys, interviews, and focus group discussions with students, staff, and community members to evaluate the project's social and educational impact.

a. Stakeholder Engagement: Surveys and interviews were conducted with various stakeholders to gather feedback on their experiences and perceptions of the project. Focus group discussions facilitated in-depth conversations about the project's impact on community awareness, attitudes toward renewable energy, and educational value for students.
b. Thematic Analysis: The qualitative data was analyzed to identify key themes and patterns, focusing on changes in community attitudes, increased awareness of renewable energy, and improvements in students' learning experiences. The analysis highlighted the project's role in fostering a culture of sustainability and environmental stewardship.
c. Educational Impact: The integration of renewable energy systems into the curriculum provided practical learning opportunities for students, enhancing their understanding of clean energy technologies and environmental responsibility. The project inspired students to actively participate in sustainability efforts, preparing them to become environmentally conscious citizens [21].

By employing this comprehensive data collection and analysis framework, the study provided valuable insights into the effectiveness and impact of the Sustainable Energy Integration project at Yayasan Widya Guna. The findings offer a robust foundation for evaluating renewable energy integration in rural communities and support the development of replicable models for sustainable development.

4 Implementation

4.1 Installation Process

Feasibility Study
The load that is installed for the needs of the Pool Therapy of the Yayasan Widya Guna with each load of 1 Pump, the total power required is 575 W, Total of load flow average on 1 day is 3,360 Wh.

Sun Peak Hour Yayasan Widya Guna
In this research, the authors also took weather data contained on the Global Solar Atlas website, where the values for irradiation and temperature on Yayasan Widya Guna were obtained as shown in table 1 as follows.

Table 1. Iradiation & air temperature data

Description	Value
Air Temperature	25.2 ºC
Average Global Horizontal Irradiation (GHI)/days	5,170 kWh/m^2

The local average irradiation was 5,170 kWh/m^2, this value was obtained from the Global Solar Atlas website using the location (–8.53181634318233, 115.29137457778678) and the equation used to determine the value of Sun Peak Hour (SPH) is as follows.

$$SPH\ (h) = \frac{Daily\ Average\ Iradiation\ (kWh/m^2)}{Insulation\ (1{,}000\ kWh/m^2)} \tag{1}$$

With equation (1) gets 5.1 h/days SPH value for Yayasan Widya Guna

Design System

The design of the stand-alone PV system implemented on Yayasan Widya Guna will be explained with several sub-chapters consisting of each characteristic of each PV mini-grid component such as solar PV, Inverters, and Batteries used. The next chapter consists of many installed loads which will later be calculated with one day of use. Weather measurements found on Yayasan Widya Guna to identify the duration of the SPH. The sub-chapters of stand-alone PV system design are as follows.

Solar Photovoltaic

The design of the solar PV technical system in order to be able to determine comprehensively needs to be calculated to determine the temperature rise of the solar panel every 1 ºC. The value is taken if the Manggur Island area experiences a temperature increase of 26.8 ºC, this data is taken from the temperature value on Manggur Island using the Global Solar Atlas, using the following equation.

$$P_{t\ increase^{o}\mathrm{C}} = 0.4\%\ ^{\circ}C \times P_{MPP} \times \Delta t(^{\circ}C) \tag{2}$$

$$P_{MPP\ saat\ t\ naik\ ^{\circ}C} = P_{MPP} - P_{t\ increase\ ^{\circ}C} \tag{3}$$

$$\mathrm{TCF} = \frac{P_{MPP\ \ t^{\circ}C}}{P_{MPP}} \tag{4}$$

It is known that if the temperature increases by 1.8 °C there is a decrease in the power capacity that will be issued. Where for the STC temperature itself is 25 ºC. According to the datasheet of the 575 Wp Jinko Solar panel used, the solar panel will reduce 0.4% of the output power by increasing the temperature above the STC temperature. The maximum output power of the Jinko Solar 575 Wp solar panel at a temperature of 26.8 ºC is 572.7 Watt. The equation for the area is as follows.

$$PV_{Area} = \frac{P}{G_{av} \times \eta_{pv} \times TCF \times \eta_{out}} \tag{5}$$

After getting the area from the calculation between the large value of electrical energy consumption (kWh) with daily solar isolation, solar panel efficiency, and the output efficiency of the Solar PV system, you can then determine the Wp value needed for this Solar PV system.

$$P_{Wp} = PV_{Area} \times PSI \times \eta_{pv} \tag{6}$$

Obtained a calculation of the peak power value of 2.2 kWp with the above calculation, but in this study the author uses a value of 2.2 kWp as the rounded power of the installed capacity. To determine the amount of solar panel capacity when using Jinko Solar 575 Wp solar panels, the following equation is obtained:

$$n\ solar\ PV = \frac{P_{Wp}}{Solar\ PV\ used} \tag{7}$$

Based on the calculations obtained 4 solar panels with a 2.2 kWp solar PV system using Jinko Solar 575 Wp solar panels (new system).

Inverter

The determination of the inverter adjusts to the load installed on the system, by adding up the total power of the pump 560 Watt using equation as follows.

$$Inverter\ (\text{VA}) = W_{maks} + (25\% \times \text{W}_{maks}) \tag{8}$$

From these calculations, the capacity of the 3.5 kW inverter has fulfilled the total installed load power, which is 560 W. This inverter was chosen because the wave output from the Growatt inverter can be modified into a pure sine wave waveform, so it can be used for loads such as Pool Therapy. In the sale of the inverter itself, the minimum output of a pure sine wave signal is at a capacity of 3.5 kW.

Battery

The design of this Solar PV system using a working voltage of 48 Volts. So that the first calculation is carried out to determine the battery voltage using the following equation:

$$Battery\ Serial = \frac{V_{system}}{V_{battery}} \tag{9}$$

It takes 1 battery in series to get a value of 48 V with CNTE Battery equals 5 kWh for capacity, the determination of the battery capacity to be used is as follows.

$$C = \frac{Ed \times AD}{Vs \times DoD \times \eta_{baterai}} \tag{10}$$

The research is limited due to costs, so the author assumes with an Ed value of 3,360 Wh, the Ed value is the total value of one day's load. With the same calculation so that the value of 211 Ah is obtained. After knowing the value of the battery capacity used, the next step is to determine the number of batteries used with the following calculations.

$$Battery\ Parallel = \frac{C}{Battery\ Capacity} \tag{11}$$

So that the value for the number of batteries required is 1 batteries.

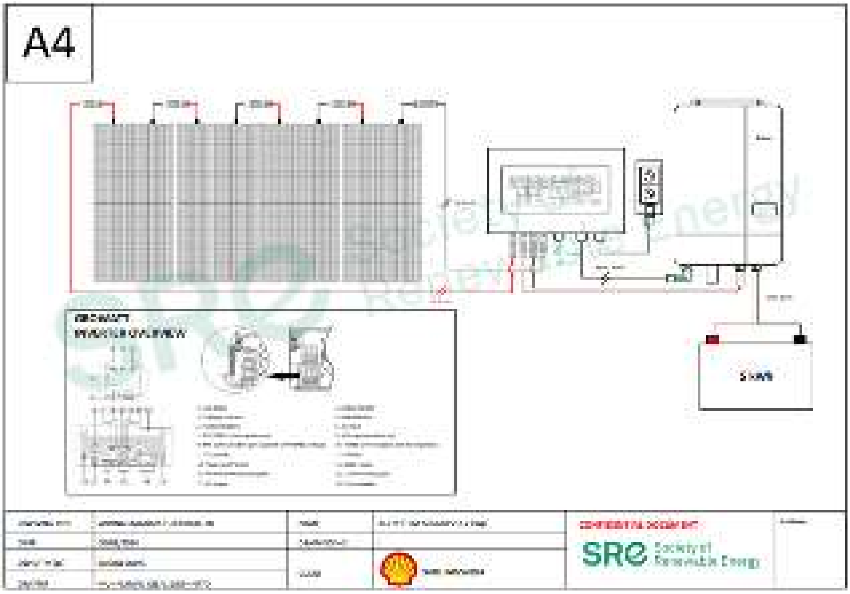


Fig. 1. All System Solar PV 2.2 kWp

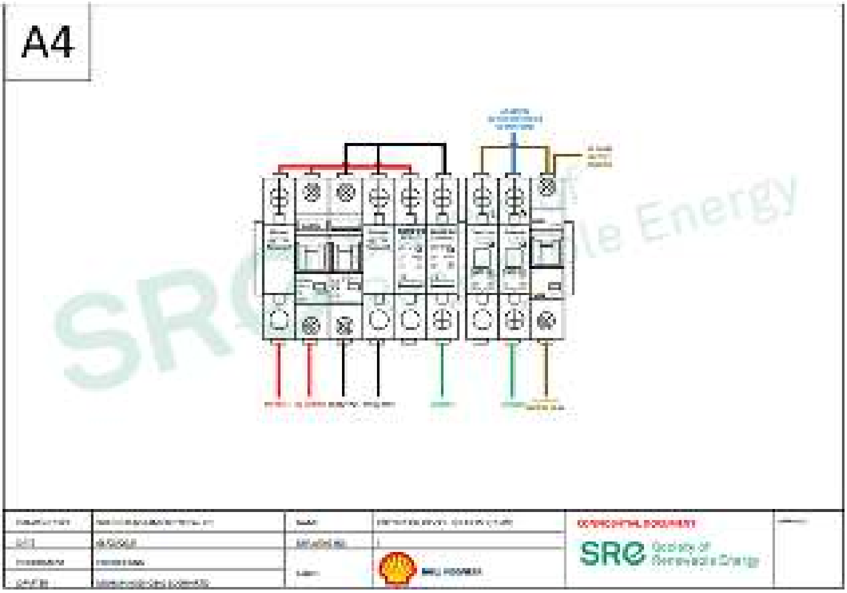


Fig. 2. Protection Device Solar PV 2.2 kWp

The type of solar panel used is monocrystalline with a datasheet as contained in the datasheet attachment and in the following table.

Table 2. Jinko Solar 575 Wp datasheet.

Description	Specification
Module Type	JKM575N-72HL4 JKM575N-72HL4-V
Power Output	575 W
Power Output Tolerances	0~+3%
Module Efficiency	22.26%
Voltage at Pmax, V_{mpp}	42.22V
Current at Pmax, I_{mpp}	13.62A
Open Circuit Voltage V_{oc}	50.88V
Open Circuit Voltage I_{SC}	14.39A
Temperature Coefficent I_{sc}	0.046%/°C
Temperature Coefficent V_{oc}	-0.25%/°C
NOCT	45±2°C

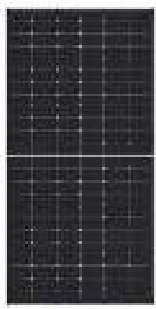


Fig. 3. Jinko Solar Monocrystalline 575 Wp

Fig. 4. Growatt Inverter SPF 3500 ES

Table 3. Inverter SPF 3500 ES.

Description	Value
Nominal Input Voltage	230VAC
Rated Output Power	3.5KVA/3.5KW
Output Voltage Waveform	Pure Sine Wave
Nominal Output Current	15.2A
Frequency Output	50 HZ
Peak Efficiency	93%
Nominal DC Input Voltage	48VDC
Max. PV Array Power	4500W
Max. PV Input Current	22A
Start-up Voltage	150VDC±10VDC
PV Array MPPT Voltage Range	120VDC~430VDC
Max. PV Charging Current	80A

Then as for the type of inverter used is the growatt brand, this type of inverter is used because the wave output is already pure sine wave and according to the specifications listed in table 4 and the attachment sheet the efficiency of this inverter has a substantial value of 93% (Growat Inverter – SPF 3500 ES).

4.2 Technical Challenges and Solutions

The analysis used to find energy-saving solutions with eco-friendly technology first calculate the existing electrical load energy by multiplying the amount of electrical load by the PLN tariff as follows:

$$Cost\ of\ Energy\ =\ Load\ Profile\ (Days) + electicity\ tariff\ (\text{Rp1,444})$$

With an average load used for a therapy pool of 560 Watt with a total average usage of 6 hours/day, a considerable amount of electrical energy is needed per year of Rp1,209,600/Month (Rp1,444 PLN electricity tariff).

The voltage drop obtained after measurment with primary data using an Avometer resulted in a voltage drop untill 210VAC. In addition to the voltage loss in the Wiguna Foundation of 2–3%, it can also interfere with the electrical load in the Wiguna Foundation. The need for a power plant that is close to the distribution of electrical loads, to reduce the voltage losses caused.

Renewable energy potential that mathces the topological conditions in the Wiguna area, specifically solar energy with GHI Value of 5,172 kWh/m2. With this GHI, a Sun Peak Hour (SPH) value of 5.1 hours/days is obtained, as mentiones in the technical calculations in section (4.1) Hybrid off grid solar power plants 2.2 kWp (New System) + 1.1 kWp (old system) are a solution to several existing problems. In addition to clean energy that does not cause air emissions during the generation of electrical energy, it can also reduce monthly electricity costs.

Not only solar energy potential for electrical energy, but cow farming also has the aspect of biogas energy as a substitute for LPG gas. In additons to reducing monthly gas bills, it also helps the country (Indonesia) reduce the amount of 3 kg LPG subsidies for low-income households.

Biogas is the second example of the use of renewable energy as a substitute for 3 kg LPG gas into energy for cooking daily consumption at the Widya Guna Foundation, by utilizing a 3 m^3 reactor can be obtained from 2–3 cows to be able to light the stove at the Yayasan Widya Guna.

4.3 Community Involvement

The interns involved in the sustainable energy integration program at Yayasan Widya Guna are mostly students from Udayana University. They play an important part in the installation and maintenance of solar panels and biogas systems. They not only come from engineering and renewable energy, but also come from non-engineering disciplines. These students assist in installing solar panels on the roof of the building, connecting the energy storage system, and ensuring all components are functioning properly. They were also involved in providing training to the foundation's staff on how to operate and maintain the renewable energy system as well as providing specialized materials on sustainable energy to the foundation's students.

In addition to interns from Udayana University, volunteers involved in this program come from various countries. They assist the foundation team in taking care of the students, providing the support and attention needed by children with special needs. These international volunteers help in daily activities, such as accompanying children during therapy sessions, assisting in teaching and learning activities, as well as supporting recreational activities and skill development. Their presence greatly benefits the students, creating an inclusive and supportive environment.

5 Result and Discussion

The Sustainable Energy Integration project at Yayasan Widya Guna has demonstrated significant improvements across multiple domains, including energy efficiency, cost savings, environmental impact, operational enhancements, and educational growth. The project, which integrates solar PV and biogas systems, has provided the center with energy independence while fostering community engagement and serving as a model for sustainable development in rural areas.

5.1 Energy Efficiency and Cost Savings

The solar photovoltaic (PV) system, with a capacity of 2.2 kWp (new system) supplemented by an existing 1.1 kWp system, has been instrumental in generating clean energy for the center. The combined systems have produced a total of 651.9 kWh since installation. The consistent generation of solar power, even during off-peak times, has made the center energy-independent. By utilizing battery storage, the system provides power during rainy weather and at night, enabling seamless operations. The financial benefit of this system is notable, with estimated savings of Rp941,669 (based on PLN electricity rates of Rp1,444 /kWh).

Fig. 5. Dashbord Monitoring System 2.2 kWp (New System)

Additionally, the biogas system has proven to be a significant contributor to cost efficiency. The system, which converts local organic waste into clean energy, produces 3 m^3 of biogas per day, effectively replacing conventional LPG for cooking and other energy needs. This has resulted in an additional monthly saving of approximately 6–7 million IDR. The combination of these renewable systems has allowed the center to redirect funds previously spent on energy to essential educational and therapeutic services, contributing to both operational sustainability and improved quality of care for the students.

5.2 Carbon Emissions Reduction

The project's environmental impact is equally significant, particularly in terms of carbon emissions reduction. The hybrid solar PV system reduces emissions by approximately 5.17 tons of CO2 per year. This reduction is based on the carbon emissions factor of the Jamali Power Distribution (0.84 ton CO_2eq per MWh) and reflects the system's ability to displace grid electricity, which is often sourced from fossil fuels.

In addition to the solar system, the biogas system captures methane, a potent greenhouse gas that would otherwise be released into the atmosphere. By processing organic waste and utilizing the resulting biogas for cooking, the system contributes to a reduction of 3.16 tons of CO2eq per year. This combined annual reduction of 8.33 tons of CO2eq highlights the project's substantial contribution to mitigating climate change. The environmental benefits of this project align with global sustainability goals and offer a replicable model for other rural communities aiming to reduce their carbon footprint.

5.3 Operational Impact

The implementation of the Sustainable Energy Integration project at Yayasan Widya Guna has significantly enhanced the center's operational efficiency, particularly in aquatherapy services and café management. The solar PV system provides a reliable energy supply to power the aquatherapy pool's heating and filtration systems, ensuring consistent operation without disruptions. This consistent energy supply enhances the quality and frequency of therapy sessions, leading to improved outcomes for students with special needs. Additionally, the shift from grid electricity to solar power has substantially reduced operational costs, allowing the center to allocate more funds to essential services and educational activities. By reducing the carbon footprint associated with the aquatherapy pool, the center aligns with its commitment to environmental sustainability and sets a positive example for students and the community.

In the cafetaria, which is managed by the students, the biogas system has been equally transformative. By replacing LPG with biogas, the café has become more cost-efficient and sustainable. This café serves not only as a practical business but also as an educational platform where students learn about sustainable energy practices and entrepreneurial skills. The hands-on experience provided by managing the café helps students develop important life skills, such as teamwork, problem-solving, and environmental stewardship. The café's reliance on biogas ensures that operations are eco-friendly, aligning with the center's overarching goal of sustainability.

5.4 Educational Impact

The integration of renewable energy systems has significantly enriched the educational programs at Yayasan Widya Guna. By incorporating practical sustainability education into the curriculum, students have the opportunity to engage directly with clean energy technologies. For example, students can observe the biogas production process firsthand, learning how organic waste is converted into energy. Similarly, the solar PV system serves as a live demonstration of how solar panels harness sunlight to generate electricity. These interactive learning experiences not only enhance students' understanding of renewable energy but also foster a sense of environmental responsibility.

The center has also incorporated renewable energy topics into its formal curriculum, teaching students about the broader relationship between technology, society, and the environment. This education empowers students to make informed decisions about energy usage and sustainability in their future endeavors. The project prepares students to face global environmental challenges with the knowledge and skills needed to participate in the transition to a low-carbon economy.

5.5 Community Impact

Community involvement has been a cornerstone of the project's success. From the outset, efforts were made to engage local community members, government authorities, and volunteers in the planning, implementation, and maintenance of the renewable energy systems. A multi-stakeholder approach ensured that the project garnered widespread support and addressed various community needs.

The key actors involved include:

a. Local Community: The local community was engaged through educational programs and workshops aimed at raising awareness about the benefits of renewable energy. This helped reduce initial resistance and built trust within the community.
b. Local Leaders: Local leaders were instrumental in advocating for the project, helping to overcome cultural and social barriers. Their endorsement increased community buy-in and fostered a sense of pride and ownership.
c. Technicians and Volunteers: Local technicians, along with international volunteers, were trained in the installation and maintenance of the systems. This not only ensured the sustainability of the project but also provided employment opportunities and skill development for the community.
d. Government and Donors: The involvement of government bodies and donors, including grants and financial support, was critical to funding the project and ensuring its long-term success.

Table 4. Community Involvement in the Sustainable Energy Integration Project.

Actor	Role in the Project
Local Community	Engaged in education and participation in maintenance
Local Leaders	Advocated for the project, building trust
Technicians & Volunteers	Installation, maintenance, and training
Government & Donors	Provided financial and logistical support

5.6 Challenges and Lessons Learned

While the project was successful, it faced several challenges, including initial community resistance, the need for ongoing maintenance, and securing sustainable funding. Resistance from the community was initially a barrier, as renewable energy technologies were unfamiliar to many. However, through educational campaigns, community meetings, and local leader involvement, this resistance was overcome. These engagements built a strong sense of ownership and trust in the project.

Another challenge was maintaining the systems over time. To address this, local technicians were trained to handle routine maintenance tasks, and a support network was established to provide access to spare parts and technical expertise when needed. This approach ensured the long-term reliability of the systems.

The project also faced financial challenges, particularly in securing funding for the installation and expansion of the systems. By developing diverse funding strategies, including government grants, private sector partnerships, and community financing models, the project was able to build a stable financial base for ongoing operations and potential future expansions.

a. Lessons Learned: The most important lesson from this project is the value of early and continuous community engagement. By involving the community from the start and addressing their concerns, the project was able to gain their support and ensure its long-term success. Additionally, flexibility and adaptability in addressing technical and financial challenges were crucial to overcoming obstacles and maintaining project momentum.
b. Scalability and Replicability: The success of the project at Yayasan Widya Guna demonstrates its potential for replication in other rural communities. By leveraging local resources, building strong community relationships, and securing diverse funding, this model can be scaled and adapted to meet the specific needs of different communities, particularly those with high energy demands and limited access to conventional electricity.

6 Conclusion

The Sustainable Energy Integration project at Yayasan Widya Guna in Rural Gianyar, Bali, has demonstrated the practical feasibility and significant benefits of integrating solar and biogas technologies in rural settings. The project's outcomes align with existing theories on renewable energy adoption, particularly in terms of cost reduction, environmental benefits, and community empowerment.

By successfully implementing a biogas system and solar panels, the project achieved substantial electricity cost savings, reducing expenses by approximately Rp6,960,000 per month. This aligns with theoretical predictions that renewable energy systems can significantly lower energy costs for rural communities. Moreover, the project's environmental impact was substantial, reducing carbon emissions by 9 tons CO2eq/year. These results support the established theory that renewable energy technologies can contribute to mitigating climate change.

The project's success can be attributed to several factors, including community involvement, technical training, and the integration of renewable energy into the center's operations. This aligns with the theory that successful renewable energy initiatives require a combination of technological innovation and community engagement. The project's impact extends beyond economic and environmental benefits, as it has also fostered a culture of sustainability and environmental awareness among the community members and students.

While the project was successful, future research could focus on long-term impact assessments, cost-benefit analysis, technical optimization, policy and regulatory frameworks, community engagement strategies, and scalability models. By addressing these areas, future initiatives can build upon the project's successes and contribute to broader efforts towards sustainable rural development and a clean energy transition.

References

1. Zohuri, B., and McDaniel, P.: Introduction to Energy Essentials. Academic Press, London (2021)

2. Chontanawat, J.: Relationship between energy consumption, CO2 emission and economic growth in ASEAN: Cointegration and causality model. Energy Reports **6**, 660–665 (2020)
3. Kirat, Y., Prodromou, T., and Suardi, S.: Unveiling the Nexus: Climate change, green innovation, and the pendulum of energy consumption and carbon emissions. Energy Economics. 107727 (2024)
4. IESR.: National Energy General Plan (RUEN): Existing plan, current policies implication and energy transition scenario. Institute for Essential Services Reform (IESR), Jakarta (2020).
5. Alhasnawi, B. N., Almutoki, S. M. M., Hussain, F. F. K., Harrison, A., Bazooyar, B., Zanker, M., and Bureš, V.: A New Methodology for Reducing Carbon Emissions Using Multi-Renewable Energy Systems and Artificial Intelligence. Sustainable Cities and Society, 105721 (2024)
6. Mukhtar, S., Muhammad, S., Alyousef, H. A., Khan, W., Shah, R., and El-Tantawy, S. A.: Enviro-economic and optimal hybrid energy system: Photovoltaic–biogas–hydro–battery system in rural areas of Pakistan. Heliyon **10**(16). (2024)
7. Gobel, R. K., Laksmono, B. S., Huseini, M., and Siscawati, M.: Equity and Efficiency: An Examination of Indonesia's Energy Subsidy Policy and Pathways to Inclusive Reform. Sustainability **16**(1), 407 (2024)
8. Mohamed, E. F., Abdullah, A., Jaaffar, A. H., and Osabohien, R.: Reinvestigating the EKC hypothesis: Does renewable energy in power generation reduce carbon emissions and ecological footprint?. Energy Strategy Reviews 53, 101387 (2024)
9. Mudhoffar, K., and Magriasti, L.: Ekonomi Politik Energi Terbarukan: Peluang dan Tantangan di Indonesia. Multiverse: Open Multidisciplinary Journal **3**(1), 47–52 (2024)
10. Halimatussadiah, A., Kruger, W., Wagner, F., Afifi, F. a. R., Lufti, R. E. G., & Kitzing, L.: The country of perpetual potential: Why is it so difficult to procure renewable energy in Indonesia?. Renewable and Sustainable Energy Reviews **201**, 114627 (2024)
11. Sah, B. P.: Geo-enabled decision support system for potential clean energy mix for Bali. Indonesia. Energy Procedia **103**, 333–338 (2016)
12. Silaen, M., Taylor, R., Bößner, S., Anger-Kraavi, A., Chewpreecha, U., Badinotti, A., and Takama, T.: Lessons from Bali for small-scale biogas development in Indonesia. Environmental Innovation and Societal Transitions **35**, 445–459 (2020)
13. Bößner, S., Devisscher, T., Suljada, T., Ismail, C. J., Sari, A., and Mondamina, N. W.: Barriers and opportunities to bioenergy transitions: An integrated, multi-level perspective analysis of biogas uptake in Bali. Biomass and Bioenergy **122**, 457–465 (2019)
14. Pusparini, T., Adhi, P., and Sari, R.P.: Renewable energy initiatives in rural Indonesia: Solar and micro-hydro solutions. Renewable and Sustainable Energy Reviews **137**, 110627 (2021)
15. Utami, P., and Saputra, D.: Deployment of solar photovoltaic systems in rural Indonesian villages. Energy for Sustainable Development **55**, 1–8 (2020)
16. Dewi, R.S., Purnomo, H., and Kusuma, H.: The Biogas Rumah (BIRU) program in Indonesia: A success story of biogas implementation. Journal of Renewable Energy **158**, 900–910 (2020)
17. Lund, H.: Renewable energy strategies for sustainable development. Energy **32**(6), 912–919 (2007)
18. Nugroho, Y.S., Rahayu, S., and Sudarmadi, H.: Performance of integrated biogas and solar PV systems in rural Indonesian households. Energy for Sustainable Development **61**, 172–180 (2021)
19. Santoso, D., Widjaja, A., and Rahman, F.: Integration of biogas and solar PV systems in rural Indonesian villages: A case study. Energy **238**, 121724 (2022).
20. Muksin, N. I. Z., Rahmi, R., & Amsir, A. A.: Kerjasama Indonesia dan Denmark dalam Membangun Energi Terbarukan di Sulawesi Selatan (Pembangkit Listrik Tenaga Bayu PLTB di Jeneponto). Jurnal Fase Kemajuan Sosial Dan Politik: Faksi **10**(1), 1–16 (2024)
21. Saleh, A. A., Ammar, M., & Andriyani, R.: Transformasi Sosial Dan Lingkungan Melalui Energi Terbarukan: Studi Dampak PLTB Sidrap Di Sulawesi Selatan. TheJournalish: Social and Government **4**(5), 263-274 (2023)

22. Daoudi, M.: Education in renewable energies: A key factor of Morocco's 2030 energy transition project. Exploring the impact on SDGs and future perspectives. Social Sciences & Humanities Open **9**, 100833 (2024)
23. Moridu, I., Purwanti, A., Melinda, M., Sidik, R. F., & Asfahani, A.: Edukasi Keberlanjutan Lingkungan Melalui Program Komunitas Hijau Untuk Menginspirasi Aksi Bersama. Community Development Journal: Jurnal Pengabdian Masyarakat **4**(4), 7121–7128 (2023)
24. Stephanie, F., and Karl, L.: Incorporating Renewable Energy Systems for a New Era of Grid Stability. Fusion of Multidisciplinary Research, An International Journal **1**(01), 37–49 (2020)
25. Gomez, M. F., and Vilar, R.: Community engagement and participation in renewable energy projects: Lessons from rural areas. Energy Research and Social Science **60**, 101337 (2020)

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