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Empowering community-based water and sanitation services through solar photovoltaic systems: A pathway to energy self-sufficiency

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ABSTRACT

Banyu Bening, an independent community group providing clean water and sanitation services, faces challenges related to energy consumption and water distribution management. The primary issue addressed was the high electricity cost for operating water pumps during the early stages of the business. This problem was particularly critical as the group was newly established and required appropriate technology to overcome these obstacles. Therefore, the main objective of this Community Service Program was to address Banyu Bening's problems—specifically, the high electricity consumption and low water pressure in the distribution network. The problem-solving process involved several steps: situation analysis, focus group discussions (FGD), material identification, assembly and testing, installation, community socialization, and evaluation. The implemented solution was the installation of a 2kWp solar power system. The final assessment revealed that the system operates optimally, successfully reducing electricity costs by 70 percent.

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1. INTRODUCTION

The "Banyu Bening" community is an independent group located in a rural area of Yogyakarta that provides clean water and sanitation services to local residents. Most members of the group work as farmers with limited financial resources. The community relies heavily on water pumps to distribute clean water, which requires a continuous supply of electricity. However, the area receives abundant sunlight throughout the year, making solar energy a promising alternative energy source. Given the group's geographic and socio-economic conditions, the potential use of solar power presents a feasible and sustainable solution to their electricity needs (Resosudarmo et al., 2023).

Banyu Bening faces significant operational challenges, primarily due to high electricity costs incurred from the daily use of electric water pumps. These costs are borne entirely by community contributions, which is unsustainable in the long term given the limited income of its members. A preliminary needs

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assessment conducted by the community service team revealed that electricity expenses accounted for more than 60 percent of the group's monthly operational budget. Additionally, technical issues such as unstable water pressure and inefficient distribution further complicate the management of the water system. These problems, if not addressed, may threaten the continuity of water services for the local population (Erdiwansyah et al., 2021; Hansen et al., 2019; Reyseliani & Purwanto, 2021).

To address these issues, the community service team proposed the installation of a Solar Power Plant (PLTS) system with a capacity of 2 kWp. This solution aims to reduce the community's dependence on conventional electricity by utilizing abundant solar energy. The intervention includes the installation of photovoltaic panels, a solar charge controller, batteries for energy storage, and an inverter system to convert DC to AC power. By integrating the solar system with the existing water distribution infrastructure, the solution is expected to provide a more stable energy supply while lowering operational costs. The design also allows for future scalability based on the community's growing energy needs (Afsharzade et al., 2016; Cao et al., 2025; Zahnd & Kimber, 2009).

Numerous studies support the effectiveness of solar energy systems in rural and low-income communities. For example, previous reserchers have shown that solar panels can significantly reduce energy expenses and enhance energy security in off-grid or underserved regions (Afsharzade et al., 2016; Benedek et al., 2018; Zahnd & Kimber, 2009). In the context of Indonesia, previous researchers emphasize the importance of integrating renewable energy sources into community development programs to support the national target of 23 percent renewable energy by 2025 (Erdiwansyah et al., 2021; Reyseliani & Purwanto, 2021). The solar system installed at Banyu Bening is projected to reduce electricity costs by up to 70 percent, providing strong quantitative evidence of its potential impact and cost-effectiveness (Boubaker & Omri, 2022; Obaideen et al., 2023; Yuan et al., 2022).

The primary objective of this community service program is to reduce electricity costs and improve the sustainability of clean water distribution in the Banyu Bening community through the implementation of a 2 kWp solar power system. This initiative is expected to support energy independence, improve access to clean water, and serve as a replicable model for other rural communities in Indonesia.

2. METHODS

The Community Service (PkM) program was implemented at the partner site, Banyu Bening, located in Mbelan, Cangkring, Mulyodadi, Bambanglipuro, Bantul, Yogyakarta. The program was conducted over a six-month period, from June to November 2024. It involved one partner group, namely the Banyu Bening community group—an independent organization that provides clean water and sanitation services to local residents.

To support the program's implementation, a hybrid solar photovoltaic system was introduced, specifically designed to meet the operational requirements of the Banyu Bening Group. The conceptual design aimed to reduce electricity-related operational costs by installing a 2 kWp Solar Power System (PLTS). The main components of the system are listed in Table 1.

Table 1. System component of solar panel electric generator

Components	Specification
Solar Panels	2 kWp total capacity
Hybrid Inverter	3 kW capacity
Battery Storage	48V/100Ah
Supports	Electrical wiring, safety equipment, and support structures

This solar power system was designed to supply electricity to power a 2 HP (1500W) water pump, lighting, and other essential equipment. Since the pump was the primary source of energy consumption, the 2 kWp system was deemed adequate to cover peak load requirements. The system was configured as a hybrid to ensure seamless transition to the national grid (PLN) during periods of low solar production or battery insufficiency.

From a technical perspective, several considerations were made during the design and implementation phases: (1) Panel Installation: Mounted 1.5 meters above the ground in a location with maximum sunlight exposure; (2) Inverter and Battery Setup: Installed indoors to ensure ease of access, maintenance, and protection from the elements; (3) System Automation: Automatic switching between solar power and PLN electricity to ensure uninterrupted operation. The program was implemented through a structured process involving several key methods:

Problem Identification and Needs Assessment

The initial stage involved direct observation and analysis of the partner's current operational challenges. Figure 1 of the original documentation illustrates this process. The primary issue identified was the high monthly electricity cost, approximately seven hundred thousand rupiah, which threatened the sustainability of Banyu Bening's operations.

Collaborative Planning through Focus Group Discussion (FGD)

To determine a feasible solution, the PkM team facilitated a FGD with the Banyu Bening team (Figure 2). The discussion involved stakeholders from both sides, and resulted in the mutual decision to install a solar power generation system as a long-term cost-saving measure.

Figure 1. Initial stage of situation observation
Figure 2. Focus Group Discussion (FGD) to identify solutions to the issues

Technical Design and System Planning

Following the FGD, the team conducted technical assessments and designed a hybrid solar system based on load analysis, spatial conditions, and budget constraints. Figure 3 displays the final system design.

System Installation and Implementation

The installation phase included testing all system components, positioning the panels, and configuring the inverter and battery. Safety, efficiency, and ease of maintenance were prioritized. Figure 4 shows the solar panel installation process.

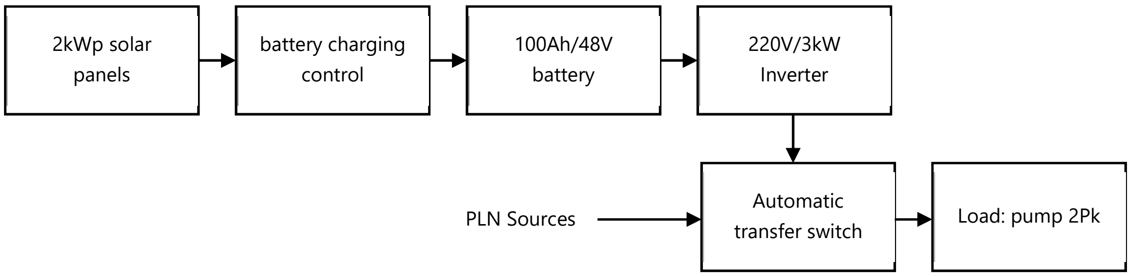

Figure 3. Design of the power generation system

Figure 4. The process of installing the solar panels

Training and Mentorship

The partner was provided with comprehensive guidance on how to operate and maintain the solar power system to ensure its long-term functionality and safety. This guidance included a technical orientation on how to operate and interpret the inverter interface, such as understanding input/output indicators, error messages, and system status lights. Detailed instructions were also given on battery maintenance procedures, including regular inspection, cleaning, charge-discharge cycles, and optimal storage conditions. In addition, safety protocols were emphasized, covering precautions during maintenance, emergency shutdown procedures, and the importance of avoiding electrical hazards. Finally, the partner was trained in basic data monitoring techniques, enabling them to track energy production, consumption, and system performance using both manual and digital tools.

Program Evaluation

The evaluation of the program was carried out through two main approaches. First, a technical evaluation was conducted by measuring key system outputs, including voltage, current, electrical load, and the resulting energy savings after the solar power system installation. Second, qualitative feedback was gathered through direct interviews with the Banyu Bening team to understand their experiences and perceptions of the system's impact. These insights were further validated by the PkM team through direct observation of daily operational activities. Quantitative indicators used in the evaluation included the reduction in monthly electricity costs, with a target savings of 70–80 percent, the amount of energy generated by the system (kWh), and the efficiency of electrical load usage along with battery utilization rates.

Program Schedule and Implementation Stages

The program was conducted over a six-month period from June to November 2024. The implementation was divided into the following stages in Table 2.

Table 2. Program schedule

Stage	Description	Objectives	Person in Charge	Timeline
Problem Identification	Field survey and energy audit at partner location	Identify operational issues and energy usage	PkM Team Leader	June 2024
Focus Group Discussion	Collaborative planning with partner	Determine feasible solution and partner commitment	All PkM Team Members & Partner	June 2024
Technical Design and Material Procurement	System design and purchase of solar components	Finalize system specs and prepare materials	Technical Lead	July 2024
System Installation	Installation of solar panels, inverter, and battery	Reduce dependence on grid electricity	Field Technicians	August 2024
Training & Mentoring	Hands-on training and maintenance orientation	Empower partner with operational knowledge	PkM Technical Team	September 2024
Evaluation	Assessment of system performance and user satisfaction	Ensure system effectiveness and sustainability	Monitoring & Evaluation Team	October – November 2024

3. RESULTS AND DISCUSSION

Results

The implemented solar power generation system consists of solar panels, batteries, and an inverter, tailored to meet the energy demands of a 2 HP (approximately 1.5 kW) water pump. To ensure reliability, a 2 kW inverter was installed, slightly exceeding the pump's power requirement. The system includes a 100 Ah, 48 V battery, ensuring the pump can operate continuously for 24 hours, even during periods of low solar radiation. The 2 kW solar panels, producing 48 V DC, are capable of both charging the battery and supporting real-time operation of the pump.

Figure 5. The components of the installed power generation system

This installation allows the partner to utilize renewable energy, reducing reliance on conventional electricity sources and lowering operational costs. Beyond the financial advantages, the technology promotes environmental sustainability, reinforcing the partner's business viability. All components of the system are depicted in Figure 5.

To support long-term functionality, the Community Service (PkM) team conducted training and socialization on the maintenance and troubleshooting of solar panel systems. The training covered practical skills such as cleaning techniques, electrical system checks, and proper handling of technical issues. This initiative, shown in Figure 6, ensures that the partner can independently manage the system and extend its service life.

Figure 6. Socialization and maintenance training.

The tangible benefit of this program is clearly reflected in the significant energy cost savings experienced by the partner. After the installation of solar panels, the Banyu Bening Group reported a reduction of approximately 70 percent in electricity expenses. Previously, their monthly electricity cost was around IDR 600,000, but it has now decreased to only IDR 200,000. This substantial cost efficiency has allowed the group to reallocate funds to other operational needs, such as facility maintenance and business development. Overall, the program has proven to be highly beneficial for the Banyu Bening Group.

Discussion

The results demonstrate that the integration of solar panel technology significantly enhances the partner's operational sustainability. The system's ability to continuously power a high-energy-demand water pump with renewable energy highlights its technical reliability and appropriateness for the partner's needs. The use of a 2 kW inverter and a sufficiently sized battery ensures stability and long-term use, especially critical for applications requiring 24-hour service.

Equally important is the sustainability of the technology through user empowerment. The training provided by the PkM team is a vital element of this initiative, addressing one of the common barriers to the adoption of renewable energy in community-based settings: lack of technical know-how. By equipping the partner with maintenance knowledge and technical problem-solving skills, the program fosters independence and prevents technology abandonment due to neglect or malfunction.

From an economic perspective, the 70 percent reduction in electricity costs underscores the viability of solar energy as a cost-saving solution. These savings are not only immediate but have a compounding effect over time, enabling reinvestment into the business and improving financial resilience. The testimonies from the Banyu Bening Group validate the program's impact, revealing improved satisfaction, reduced financial stress, and greater flexibility in managing resources.

In a broader context, this program exemplifies a successful community-based renewable energy model that integrates technology, training, and economic benefit. It aligns with sustainable development goals by promoting clean energy, reducing environmental impact, and empowering local communities. As emphasized in the literature (Hindarto et al., 2021; Mekhilef et al., 2013; Torshizi & Mighani, 2017) such integrated approaches are essential in ensuring long-term adoption and success of renewable energy systems, particularly in underserved or rural communities.

4. CONCLUSION AND RECOMMENDATIONS

The solar panel installation program and the improvement of the water flow rate have significantly impacted the partner group's operational activities. The 70 percent savings on electricity costs thanks to solar panels have enabled the partner to allocate funds more efficiently, allowing reinvestment into other needs such as facility maintenance. This has made the group's operations more financially independent and sustainable. The impact of this program is not only felt in one aspect but holistically, where financial and technical aspects complement each other. The energy savings and increased water distribution capacity bring mutually reinforcing benefits, strengthening the long-term sustainability of the partner group. This program has created synergy between operational efficiency and service enhancement, ultimately improving reputation and customer satisfaction.

It is recommended that the partner establish a regular monitoring system to track the performance of both the solar power system and the water distribution system. This should include recording energy production, battery usage, load efficiency, and their impact on daily operations. Ongoing monitoring is essential to maintain efficiency, detect potential technical issues early, and ensure the long-term sustainability of the program's benefits. Given the program's success in improving operational efficiency and financial independence, it is advisable to consider replicating this model in other communities with similar needs. The partner can serve as a case study and mentor for other groups interested in adopting comparable systems, thereby expanding the positive impact on a regional scale. To further strengthen the program's long-term impact, it is recommended to provide the partner with continued training—not only in the technical aspects of energy and water systems, but also in financial management, investment planning, and customer service development. This will help the partner organization manage resources more effectively and foster holistic organizational growth.

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