International Journal of Community Service
ISSN: 3083-9696

Community Service on Solar PV Integration for Smart Farming Irrigation Systems in Islamic Boarding Schools

Muhibbuddin[1], Mahidin[2], Asri Gani[2], Erdiwansyah[3,4], Syafrizal[5], Harbiyah[6], Muhammad Zaki[2], Bahagia[5], Friesca[7]

[1]Department of Mechanical and Industrial Engineering, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
[2]Department of Chemical Engineering, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
[3]Department of Natural Resources and Environmental Management, Universitas Serambi Mekkah, Banda Aceh 23245, Indonesia
[4]Centre for Automotive Engineering Centre, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan 26600, Malaysia
[5]Department of Environment Engineering, Universitas Serambi Mekkah, Banda Aceh, 23245, Indonesia
[6]Department of Hospitality, Faculty of Vocational Studies, Universitas Muhammadiyah Aceh
[7]Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia

Corresponding Author: muhib@usk.ac.id

Abstract
Adopting renewable energy technologies in agriculture is essential for promoting sustainable development in rural educational institutions. This community service initiative was carried out at an Islamic boarding school to integrate a solar photovoltaic (PV)-powered smart irrigation system to support food production and environmental awareness. The project was designed to improve water-use efficiency and serve as a living laboratory for students. Site assessments, technical measurements, and infrastructure evaluations were conducted to ensure system compatibility with the local topography and farming conditions. Key methods included field observation, readiness assessment of water tower structures, and detailed planning of pump installation using real-time measurements. The results revealed that the site has a suitable spatial layout, stable infrastructure, and consistent water availability to support a gravity-fed irrigation system. A significant finding is the feasibility of combining school farming activities with solar-based automation without disrupting the educational environment. The novelty of this work lies in its interdisciplinary approach, which bridges renewable energy engineering, smart agriculture, and religious-based education. The system design is context-sensitive, scalable, and replicable for similar institutions. In conclusion, this project demonstrates that small-scale smart farming powered by solar PV can be technically and socially integrated in boarding school settings, offering environmental and educational benefits. The authors recommend further monitoring system performance and exploring digital sensor integration in future phases.

Article Info	Keywords
Received: 08 April 2025	Solar Photovoltaic
Revised: 12 May 2025	Smart Irrigation
Accepted: 15 May 2025	Islamic Boarding School
Available online: 30 June 2025	Community Service
	Sustainable Agriculture

1. Introduction

Modern agriculture faces increasing challenges related to water scarcity, energy dependency, and climate variability. Efficient water and energy management is particularly crucial in rural areas, where conventional infrastructure is often limited. Smart irrigation systems powered by renewable energy sources, especially solar photovoltaic (PV) technology, offer a sustainable solution to improve agricultural productivity while reducing environmental impacts [1–4]. Previous research has demonstrated the effectiveness of solar-powered irrigation systems in various contexts. For example, solar pumping has been widely adopted in arid regions to reduce reliance on diesel generators, contributing to lower greenhouse gas emissions and operational costs. Solar irrigation can increase crop yield by ensuring consistent water delivery, even in off-grid or semi-rural environments [5–8].

In parallel, precision agriculture and automation have gained traction through sensors and smart controllers that optimise irrigation based on real-time data such as soil moisture and weather conditions [9–12]. When combined with renewable energy, such systems create a closed-loop approach to sustainable farming. However, implementation remains limited in educational or community-based agricultural systems, especially in Southeast Asia. Islamic boarding schools (pesantren) often operate agricultural plots for food self-sufficiency and student training [13–16]. These schools present a unique opportunity to introduce and model sustainable agricultural innovations. Despite their potential, few studies or interventions have focused on integrating solar-powered smart irrigation within religious educational institutions. This community service initiative was designed to fill that gap by implementing a solar PV-based smart irrigation system in an Islamic boarding school setting [17–20]. The program aimed to improve irrigation efficiency on the school's farmland and empower students and staff with knowledge and skills in renewable energy and sustainable agriculture. The school community's involvement was central to the success and sustainability of the project.

The project applied a combination of technical surveys, field assessments, and infrastructure evaluations to ensure that the system design was tailored to the specific needs and constraints of the location [21–24]. Factors such as land layout, water tower stability, and pump placement were carefully considered to ensure optimal system performance and ease of maintenance. Furthermore, this initiative contributes to the growing knowledge of community-based renewable energy applications. It offers a replicable model that bridges environmental sustainability with education and community development, aligning with global goals such as SDG 4 (Quality Education) and SDG 7 (Affordable and Clean Energy). The specific objectives of this community service project were: (1) to design and install a solar PV-powered smart irrigation system suited to the boarding school's agricultural plot; (2) to assess the technical feasibility and site readiness of infrastructure components; (3) to engage students and staff in training sessions related to system operation and maintenance; and (4) to document and disseminate findings for replication in similar educational institutions.

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2. Methodology

This community service project employed a participatory engineering approach, integrating technical design, field-based assessments, and community engagement to implement a solar PV-powered smart irrigation system in an Islamic boarding school. The methodology was structured into four main phases: (1) site assessment and planning, (2) infrastructure evaluation, (3) system design and pre-installation, and (4) community training and documentation.

1) **Site Assessment and Planning**
   Initial observations were conducted to identify potential locations for the solar panels, water pump system, and irrigation field layout. The project team performed direct field inspections (**Figures 1** and **2**) to evaluate sun exposure, proximity between the water source and agricultural area, and accessibility for equipment and maintenance. Spatial mapping was done using manual measurement tools to determine the optimal distances between infrastructure components (**Figure 6**).

2) **Infrastructure Evaluation**
Existing infrastructure, including the water tower, well, and electrical connections, was inspected for structural stability, material integrity, and integration feasibility (**Figures 3** and **5**). Measurements of the water tower platform height, pipe inlet location, and foundation dimensions were recorded to verify compatibility with the solar-powered pumping system.

3) **System Design and Pre-installation**
The irrigation system was designed to utilise a gravity-fed water distribution, with a submersible or surface solar pump connected to the PV panel array. Based on local solar irradiation data, the team calculated the total dynamic head (TDH), flow rate requirements, and solar panel sizing. Smart irrigation features, such as soil moisture sensors and automatic timers, were planned for future integration.

4) **Community Training and Documentation**
Workshops and informal technical briefings were conducted with school staff and selected students to ensure system operation, safety, and maintenance knowledge transfer. Each implementation step was documented through photographs, diagrams, and field notes to support replicability in other institutions.

The authors worked collaboratively throughout all stages, contributing technical expertise, financial resources, and field labour. The methodology was designed to be context-sensitive, with adjustments made based on real-time site conditions and feedback from the school community.

3. Result & Discussion

Figure 1 shows the general environment of the Islamic boarding school that has been selected as the site for implementing a solar photovoltaic (PV)-based smart irrigation system. The image captures various key infrastructures, including classrooms, dormitories, and recreational areas, indicating the institutional readiness for a structured community service initiative. The presence of open land, accessible roadways, and available electrical connections highlights this site's suitability for deploying renewable energy systems. Furthermore, the strategic location within the school compound allows for ease of monitoring, maintenance, and student involvement in learning-based activities associated with solar PV and irrigation technologies. The view also suggests the potential for integration between the educational function of the school and the applied use of green technology for agricultural purposes, aligning with the goals of sustainability and community empowerment.

Figure 1: View of the Islamic Boarding School Environment as the Location for Solar PV-Based Smart Irrigation System Implementation

As seen in the figure, the site layout also offers ample space for future expansion of renewable energy infrastructure. Areas such as the open field and surrounding greenery can be further developed to include additional solar panels, drip irrigation systems, or even educational signage to support environmental literacy among students. The image also indicates a conducive and safe environment for training and practical demonstrations, essential to the community service program's educational objectives. Moreover, the structured campus environment signifies a high level of organisation, which is critical for project sustainability. The centralised layout is expected to facilitate coordination with school administrators, teachers, and students. The school's interest in adopting an intelligent irrigation system powered by solar energy addresses practical water management needs and serves as a living laboratory for integrating science, technology, and Islamic education. Thus, **Figure 1** visually confirms that this location is appropriate for the intended solar PV integration and its long-term benefits in agriculture and education.

Figure 2 presents the agricultural land area within the Islamic boarding school designated for implementing a smart farming irrigation system powered by solar energy. The land is already segmented into planting beds, covered with plastic mulch, indicating that the area is actively used for cultivation and ready for technological enhancement. The photo also shows surrounding vegetation and partial irrigation infrastructure, demonstrating that the location is well-suited for integrating a smart irrigation system to improve water efficiency and crop productivity. The surrounding facilities, including fencing and nearby access roads, ensure that the area is secure and logistically accessible for installing and maintaining solar-powered irrigation equipment. Additionally, the proximity to water sources and utility structures (such as the elevated tank seen in other figures) strengthens the potential for seamless integration of solar pumps, moisture sensors, and automated watering controls. This infrastructure is critical for real-time irrigation management based on crop needs and weather conditions.

Moreover, using this land for demonstration purposes is expected to provide educational benefits to the boarding school students. It can serve as a living laboratory where students gain hands-on experience with green technologies and sustainable agriculture practices. The initiative supports food self-sufficiency at the institutional level and promotes environmental awareness and technical skills aligned with future farming innovations.

Figure 2: Agricultural Land Area for Smart Farming Irrigation System in the Islamic Boarding School

Figure 3 displays a water tower structure installation site that will serve as the primary water distribution point for the solar PV-powered smart irrigation system. The image shows the physical structure supported by four concrete pillars and topped with a steel platform, intended to hold a water tank. Two individuals, including one in a safety vest and helmet, are seen inspecting and measuring the structure, indicating the site is under active preparation for system integration. The overhead wires and conduit visible in the image suggest that electrical planning is already underway, which is essential for connecting the solar PV array to the water pump system. The elevated platform ensures gravitational water flow, a key component in energy-efficient irrigation, especially when coupled with solar-powered pumping. The structure's positioning within a secure and enclosed area further ensures protection from environmental hazards and unauthorised access, supporting long-term sustainability.

Additionally, the involvement of technical personnel highlights the collaborative and professional approach taken in the system design and implementation. This step is critical for ensuring structural safety, system compatibility, and optimal pump performance. The successful establishment of this infrastructure will serve as a central node in the overall irrigation network, distributing water to the agricultural fields shown in the previous figures while demonstrating the practical application of renewable energy in school-based farming environments.

Figure 3: Installation Site of Water Tower Structure for Smart Irrigation System with Solar PV Integration

Figure 4 illustrates a field observation conducted at the agricultural plot designated for solar-powered smart irrigation system implementation. A project team member, equipped with standard safety gear, is standing in the middle of the field, suggesting an active site survey and environmental assessment. The field is structured into multiple planting beds, covered with plastic mulch, indicating that the land is prepared for or engaged in cultivation activities. This observation phase is crucial for determining the irrigation system's optimal layout and technical requirements, including pipe routing, emitter placement, and solar pump positioning. The uniform design and open visibility of the plot support efficient planning of water distribution zones, which is essential for smart irrigation control based on soil moisture sensors and weather data. Supporting buildings in the background suggest logistical convenience for maintenance, monitoring, and integration with school-based learning activities.

Furthermore, the documentation of this step underscores the project's commitment to responsible engineering practice and sustainable technology adoption. Involving an on-site evaluation ensures that the system design is tailored to the boarding school's specific topography and agronomic conditions. Ultimately, this careful observation supports creating a replicable model of solar-powered smart farming that combines environmental stewardship, technological innovation, and educational empowerment. In addition, this field observation provides essential baseline data regarding land slope, crop spacing, and soil texture, which are necessary variables in designing a responsive irrigation schedule. By incorporating such physical insights into system development, the project team can improve overall water-use efficiency and avoid over- or under-irrigation. This step bridges practical field realities with data-driven decision-making to ensure the smart irrigation system operates effectively and sustainably.

Figure 4: Field Observation of Agricultural Plot for Solar-Powered Smart Irrigation Implementation

Figure 5 captures the readiness assessment of the water tower infrastructure used in the solar PV-powered irrigation system. A field technician in the foreground is equipped with personal protective equipment (PPE) and a measuring tool, indicating that site inspection and technical evaluation are actively being conducted. The tower structure's concrete pillars and metal frame appear to be in stable condition, offering a strong foundation for installing a water tank and connecting it to the solar pump system. The site is adjacent to the agricultural field, ensuring minimal energy loss and maximum efficiency when pumping water to the desired irrigation zones. The presence of visible piping and electrical wiring in the background suggests that partial groundwork for electrical integration has already been laid. This proximity between infrastructure components, water source, tower, field, and electrical input optimises the design for ease of installation, operation, and maintenance.

In the broader context of sustainable development, this infrastructure assessment is essential for verifying load capacity, water tank volume suitability, and system durability under local environmental conditions. The project team can mitigate potential system failures by conducting thorough pre-installation checks, meeting safety standards, and confirming the structure’s compatibility with the chosen solar pump specifications. This step reflects the commitment to quality assurance when deploying renewable energy technologies. Additionally, the visual documentation of this process contributes to transparency and replicability of the initiative, which is valuable for scaling up similar projects in other Islamic boarding schools. It serves as a reference for best practices in the field, helping future implementers understand the technical and logistical prerequisites involved in building solar-powered irrigation systems that are both reliable and community-centred.

Figure 5: Readiness Assessment of Water Tower Infrastructure for Solar PV Pumping System

Figure 6 illustrates the measurement and preparation activities for installing a water pump system integrated with solar energy to support smart irrigation. Two individuals are shown conducting precise distance measurements around a well, with one holding a measuring tape and the other acting as a reference point. This step is essential in ensuring accurate alignment and spacing between structural components such as the pump, support frame, and water delivery pipes. Precise measurements at this stage play a critical role in system design, as they directly affect pump efficiency, water flow rate, and hydraulic head estimation. Proper positioning also minimises material waste and ensures ease of maintenance access. In the context of a solar-powered system, spatial coordination is vital to guarantee that the pump and control components are optimally located relative to the solar panels, battery bank (if any), and the irrigation field.

The open access around the well and supporting structure, as shown in the image, provides a practical workspace for installation and later inspections. The concrete casing of the well appears solid, indicating the availability of a reliable water source. This foundational work serves as a prelude to installing sensors, piping systems, and PV-driven pumping mechanisms to collectively form a responsive, automated irrigation solution tailored to local needs. Finally, this image underscores the importance of field-based precision in engineering tasks, especially within renewable energy and agricultural systems. By documenting and carrying out site-specific measurements, the team ensures that the design process is rooted in real-world conditions, enhancing the overall effectiveness and durability of the smart irrigation infrastructure. It reflects integrating practical skills with sustainable technology in a community service context.

The implementation of a solar PV-based smart irrigation system in an Islamic boarding school, as presented through **Figures 1** to **6**, represents a novel interdisciplinary approach that integrates renewable energy, precision agriculture, and educational empowerment within a faith-based institutional context. Unlike conventional irrigation systems in rural schools or communities, this initiative combines real-time field assessments, solar-powered infrastructure design, and smart water management tailored to the spatial and agronomic characteristics of the site. This creates a context-sensitive model for sustainable agricultural development that is still rare in Southeast Asian pesantren environments. One key novelty lies in the system integration method, where a gravity-fed water tower is optimised with solar PV and smart irrigation controls, such as automated water pumps and moisture-based scheduling. The rigorous technical groundwork from land layout analysis (**Figures 2** and **4**), water tower readiness (**Figures 3** and **5**), to on-site measurements (**Figure 6**) ensures that the system is engineered with both environmental adaptability and operational efficiency. This differs from many off-the-shelf solar irrigation kits, which are often implemented without localised calibration or engineering validation.

Figure 6: Measurement and Preparation of Water Pump Installation for Solar-Powered Irrigation System

Another innovative aspect of the project is its dual-purpose framework: while solving a practical challenge (water efficiency in school farming), it also functions as a living laboratory for student learning and capacity building. The boarding school setting allows the system to be embedded in the educational curriculum, fostering awareness and skills in sustainable technology among students. This educational integration significantly enhances the socio-technical impact of the project, turning a technical intervention into a scalable community-based innovation. In summary, the novelty of this initiative lies not only in the technical solution but in the holistic design that simultaneously addresses energy, education, and food security. It bridges the gap between engineering innovation and community development through contextual adaptation, making it a replicable model for Islamic schools and rural communities seeking sustainable farming solutions powered by clean energy.

4. Conclusion

Integrating a solar photovoltaic (PV)-powered smart irrigation system within an Islamic boarding school environment demonstrates a practical and innovative model for sustainable agricultural development in educational institutions. The project has successfully aligned renewable energy technology with localised farming needs through comprehensive field assessments, including site surveys, water tower evaluations, pump installation planning, and agricultural layout analysis. The results highlight that the system is technically feasible, contextually appropriate, and educationally valuable. Each component from the solar pump and water tower to the thoughtful irrigation planning was carefully calibrated to suit the school's infrastructure and agricultural conditions. Moreover, the participatory approach involving direct observation, measurement, and collaboration between engineers and educators reflects a commitment to long-term system reliability and knowledge transfer. Ultimately, this initiative provides an environmentally friendly irrigation solution and serves as a living classroom that promotes green technology literacy among students. The novelty lies in its interdisciplinary integration of solar energy, precision irrigation, and educational empowerment, making it a replicable framework for other boarding schools and rural communities aiming to achieve sustainability through technology-driven community service.

Acknowledgement

The authors would like to express their sincere gratitude to all individuals and institutions who supported the implementation of this community service project. This work was fully funded through all authors' contributions and collective support. Their dedication, both intellectually and financially, made this initiative possible. We also extend our appreciation to the staff and students at the Islamic boarding school for their cooperation and enthusiasm throughout the planning and installation phases of the project.

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