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Implementation of a Solar-Powered Irrigation Pump and Capacity Building for a Farmer Group in Bune Village: Toward Renewable Energy-Based Irrigation

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ABSTRACT

The Rumpuleng Farmer Group in Bune Village, Bone Regency, Indonesia, faces limited irrigation water in rainfed rice fields and relies on fuel-powered pumps. This community engagement program aimed to implement a solar-powered irrigation pump while improving the group's technical capacity and management. A participatory technology-transfer approach was applied in five stages: observation and socialization, equipment inspection, technical and managerial training, installation and commissioning, and mentoring and evaluation. Competency was assessed with a one-group pre-test and post-test administered to 16 participants; each indicator was scored as a percentage of the maximum attainable score and reported at the group level, with the change expressed in percentage points and as normalized gain. Scores increased from 30% to 85% for assembly, from 10% to 90% for maintenance, and from 15% to 95% for operation. Technology literacy and management understanding reached 100% at endline, without a comparable baseline. The installed system comprised two 250 W photovoltaic modules and a 400 W AC submersible pump; the 50 L/min flow target and fuel-use reduction were program targets and have not been field-measured. The results indicate that combining equipment, hands-on practice, standard operating procedures, and mentoring was associated with higher post-test competencies in assembling, maintaining, and operating the system; without a control group or individual-level data, these gains are descriptive and cannot be generalized. Field monitoring of flow rate and fuel savings is the next step to verify the technical-economic benefits.

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INTRODUCTION

Water availability is a major limiting factor in rainfed rice fields, particularly when the dry season prolongs periods without an adequate supply of surface water. Under such conditions, farmers generally rely on fuel-powered pumps to maintain irrigation, but this practice increases operating costs and reinforces dependence on fossil energy. Experience with solar-powered water pumping in rice fields in Lampung has demonstrated that photovoltaic systems can serve as decentralized energy sources for irrigation pumping; in that study, a 200 Wp photovoltaic system coupled with a 60 W DC pump achieved a flow rate of up to 29 L/min at a 4 m head (Sinaga et al., 2021).

The application of photovoltaic technology for water pumping has also expanded across various agricultural contexts. Budiyanto et al. (2021) reported the use of solar electricity to operate submersible pumps in hydroponic greenhouses, while Syahid et al. (2022) implemented solar-powered pumps for agricultural irrigation systems and developed an automated watering system based on solar-powered pumping. At the rice-field scale, Wardana et al. (2023) demonstrated the application of solar-powered pumping integrated with a monitoring system, whereas Supriyono et

al. (2024) reported a solar-powered pumping system with a capacity of 30 L/min for irrigation facilities and renewable energy education. These findings indicate that solar-powered pumping systems are not merely energy devices but also appropriate technologies that must be adapted to flow-rate requirements, pumping head, photovoltaic capacity, pump characteristics, and operational patterns.

Beyond technical design, human and institutional factors are equally important. The solar-alternative energy-based water pump education conducted by Hamdani et al. (2024), the photovoltaic system assembly training reported by Syahid et al. (2024), and the implementation of solar-powered pumping for fish farming by Sa'adah et al. (2024), demonstrate that technology dissemination, hands-on practice, maintenance, and monitoring are integral to successful technology adoption. Maghfiroh et al. (2024) also emphasized the integration of irrigation management, photovoltaic system introduction and assembly, and maintenance training within farmer groups. In 2025, Sudarmaji et al. (2025) implemented an off-grid solar-powered pumping system without battery storage for rice-field irrigation, while Yuniarti et al. (2025) reported the utilization of solar energy to reduce electricity dependence in hydroponic systems. These SINTA-indexed studies further support the view that technology transfer should be designed as a process of learning and asset management rather than merely as the handover of equipment.

The Rumpuleng Farmer Group in Bune Village, Libureng District, Bone Regency, was selected as the partner because it faces two interrelated challenges: limited water availability in rainfed agricultural land and high dependence on fuel-powered irrigation pumps. In addition, the group's competencies in equipment assembly, operation, maintenance, and the operational management of renewable energy technology require further strengthening. Therefore, the intervention was designed to integrate a solar-powered irrigation pumping system with hard- and soft-skill training, standard operating procedures (SOPs), operational logbooks, and continuous mentoring.

Despite this growing body of work, several limitations remain in the community-based solar irrigation programs reviewed here. First, several reports emphasize equipment delivery or system design, with technical performance described through a single configuration or flow rate (Sinaga et al., 2021; Supriyono et al., 2024), while capacity-building components are often described qualitatively. Second, programs that emphasize education or training (Hamdani et al., 2024; Syahid et al., 2024) often do not link competency outcomes to an installed irrigation system operated by the farmer group itself. Third, reports from larger-scale installations (Sudarmaji et al., 2025) address system sizes and service areas that differ from those of smallholder rainfed rice groups with limited capital.

Finally, among the reports reviewed, few explicitly separate competencies that were measured from technical targets that remain unverified, which limits how far their results can be interpreted. Consequently, evidence on how a small-scale solar pumping system, operator training, and group-level asset management can be combined, and what can and cannot yet be claimed from such a program, remains limited. This article therefore offers a descriptive account of one community engagement program rather than a test of its effectiveness: it measures competencies aligned with the training content (assembly, maintenance, and operation) before and after the intervention for a single partner group, and reports technical performance targets separately from measured outcomes.

This article aims to scientifically document the implementation process and outcomes of the program, focusing on three aspects: (1) changes in the partners' technical competencies (assembly, maintenance, and operation) based on pre- and post-test data from 16 participants; (2) the implementation status of the technology and the limitations of the available technical performance data; and (3) the sustainability mechanism through SOPs, role allocation, and systematic record-keeping. The practical novelty of this intervention lies in integrating photovoltaic pumping technology, operator competency development, and farmer-group asset management within a single intervention framework that can be replicated with appropriate adjustments to local hydraulic and energy conditions.

METHOD

Location, Partners, and Activity Design

The activity was conducted in collaboration with the Rumpuleng Farmer Group in Bune Village, Libureng District, Bone Regency, Indonesia. The participants were 16 group members, consisting of 3 core management committee members and 13 members. The approach adopted was participatory technology transfer, in which the partners were actively involved throughout the process, including needs identification, site selection, component familiarization, installation practice, system operation, maintenance, and evaluation. The activity was structured into five stages: (1) preliminary observation and socialization; (2) procurement and inspection of equipment and materials; (3) technical and organizational management training; (4) technology implementation and installation; and (5) mentoring and evaluation. The evaluation used a one-group pre-test and post-test design.



Figure 1. Activity implementation stages, reported outcomes, and data verification status

PV–Pump System Configuration

The system configuration is summarized in Table 1.

Table 1. PV–pump system specification

Component	Specification
PV module	Sunman, 250 W rated power, 2 modules (The circuit used is a series circuit)
Pump	AC submersible, 400 W rated power
Controller/inverter	Pure sine wave 24 V (input, DC) to 230 V (output, AC), 2.000 W, 50 Hz
Energy storage	2 x 12 V, 120 Ah (The circuit used is a series circuit)
MPPT	EPEVER® Tracer 3210AN 12V/24V 30A
Piping	PVC, diameter 3 in, length 100 m

Intervention Stages

The first stage involved preliminary observation and socialization to identify water sources, irrigation patterns, installation sites, existing fuel-powered pump usage, operational risks, and prospective operators. The second stage involved inspecting and verifying the system components, comprising two 250 W photovoltaic (PV) modules connected in series, a 400 W AC submersible pump, a 2,000 W pure sine wave controller/inverter (24 V DC input, 230 V AC output, 50 Hz), two 12 V, 120 Ah batteries connected in series, an EPEVER® Tracer 3210AN 30 A MPPT charge controller, and PVC piping with a 3-inch diameter and 100 m length. The third stage involved technical training through demonstrations and group-based hands-on practice, covering component identification, electrical safety, basic connections, system operation, troubleshooting, maintenance, task allocation, standard operating procedures (SOPs), and fault recording.

The fourth stage consisted of system installation and commissioning, including PV module mounting, electrical connections, installation of the MPPT controller, 24 V battery bank, inverter, submersible pump, and piping system. Partner operators actively participated through a learning-by-doing approach Hasbi et al. (2025). The fifth stage involved continuous mentoring, focusing on PV module cleanliness, battery condition, electrical connections, pump performance, piping inspection, operating hours, troubleshooting, and the implementation of SOPs and logbooks. This approach is

consistent with technology transfer practices reported in SINTA-indexed community engagement studies, which integrate technology installation, technical training, and continuous mentoring (Budiyanto et al., 2021; Maghfiroh et al., 2024; Wardana et al., 2023).

Evaluation Instruments and Data Analysis

Competency was evaluated using a one-group pre-test and post-test administered to the 16 participants before the training and after the mentoring stage. Three indicators had both baseline and endline data: system assembly, maintenance, and operation. [Authors to complete: test format (written and/or practical), number of items per indicator, scoring rubric, and assessor.] Each indicator was scored as a percentage of the maximum attainable score. The values reported here are group-level scores per indicator, not the proportion of participants who passed; individual-level scores were not available for analysis. The change in competency was calculated as Δ = post-intervention score − pre-intervention score and expressed in percentage points. The overall pre- and post-intervention values were calculated as the unweighted arithmetic mean of the three indicator-level scores. For additional descriptive interpretation, the normalized gain (Hake, 1998) was calculated at the indicator level using the following equation (1) and interpreted as high ($g \geq 0.70$), medium ($0.30 \leq g < 0.70$), or low ($g < 0.30$):

$$g = \frac{post - pre}{100 - pre} \quad (1)$$

Inferential statistical tests were not performed because individual-level observations, standard deviations, and score distributions were unavailable, and the one-group design has no comparison group.

Table 2. Evaluation indicators and evidence status

Indicator	Available Data	Analysis Method	Scientific Status
Assembly	30% → 85%	Δ and normalized gain	Measured outcome reported in source material
Maintenance	10% → 90%	Δ and normalized gain	Measured outcome reported in source material
System operation	15% → 95%	Δ and normalized gain	Measured outcome reported in source material
Technology literacy/ management	Endline: 100%	Descriptive endline	Baseline not available
Pump flow rate	Target ≥50 L/min	Volume–time measurement/ flow log	Not yet verified
Fuel consumption reduction	Target up to 100%	Pre–post fuel consumption log	Not yet verified

Technology literacy and management understanding were reported only with final scores of 100%, which could be verified from the available source materials. Because numerical baseline scores were unavailable, gain values were not calculated for these indicators. Similarly, the minimum target flow rate of 50 L/min and the target fuel-consumption reduction of up to 100% in the intervention area were treated as program targets rather than measured outcomes, because flow-rate measurement sheets and pre–post fuel-consumption logs were not available. This distinction was maintained to ensure the validity and transparency of the reported findings. Table 2 summarizes the indicators, analysis methods, and evidence status.

RESULTS AND DISCUSSION

Implementation and Outcomes of Each Stage

The preliminary observation and socialization stage resulted in the identification of water requirements, the proposed installation site, and the initial allocation of roles among the partner group. The attendance of the management committee and core members was reported at 100%, the program involved 16 participants in total (3 core management committee members and 13

members). Component inspection was conducted prior to installation to minimize the risk of system failure during commissioning. During the training stage, the most evident changes were observed in technical competencies. The subsequent installation process served as a hands-on learning platform, enabling operators not only to receive technical explanations but also to repeatedly practice basic operating and inspection procedures. During the mentoring stage, standard operating procedures (SOPs) and logbooks were positioned as instruments to support the sustainability of system operation and maintenance.

This staged intervention model is consistent with approaches reported in similar community engagement programs. Sinaga et al. (2021) combined education with the implementation of a solar-powered pumping system, Syahid et al. (2022) integrated training with demonstrations of an irrigation system; Supriyono et al. (2024) incorporated operational and maintenance training; while Maghfiroh et al. (2024) structured training around irrigation management, photovoltaic system assembly, and maintenance. Thus, the outcomes achieved in Bune Village can be understood as the result of interaction between the physical technology and hands-on learning experiences, rather than merely as a one-way transfer of information.

Enhancement of Partners' Technical Capacity

The technical competencies of 16 participants were summarized across three indicators: pump and PV panel assembly, pump and PV panel maintenance, and system operation. Each indicator was assessed using the performance-observation instrument, with a maximum score of 20 for assembly (10 work steps scored 0–2) and 16 for maintenance and system operation (8 work steps scored 0–2). Participant scores were converted into percentages by dividing the score obtained by the relevant maximum score and multiplying by 100. The mean percentage for each indicator was then calculated across the 16 participants.

Table 3. Recapitulation of the 16 Participants' Competency Scores

No.	Participant	Pump And PV Panel Assembly		Pump And PV Panel Maintenance		System Operation	
		Pre	Post	Pre	Post	Pre	Post
1	Agustang	6	16	2	14	4	16
2	Sonna Wing	6	17	1	14	3	16
3	Yusuf	5	17	2	15	3	16
4	Musriadi	7	17	3	15	4	16
5	Darmawan	6	17	2	15	3	16
6	Budiyanto	6	18	1	14	2	15
7	Hara	8	18	2	14	2	14
8	Edi	5	16	1	14	2	15
9	Odding	6	18	2	15	2	15
10	Janudding	6	16	2	14	3	15
11	Calir	7	18	2	15	2	15
12	Eril	5	17	1	14	2	15
13	Emil	5	15	1	13	2	14
14	Muliadi	6	17	1	14	1	14
15	Cahu	6	18	1	15	1	15
16	Bedu	6	17	2	16	2	16
Maximum Score		20	20	16	16	16	16
Mean Score		6	17	1,63	14,43	2,38	15,29
Mean Score (%)		30	85	10	90	15	95
Improvement (percentage points)		55		80		80	

The participant-level scores presented in Table 3 provide the basis for evaluating changes in partners' technical competencies following the training intervention. To facilitate a comparative assessment, the individual scores were converted into percentages and aggregated to obtain the mean pre- and post-intervention scores for each competency indicator. The differences between these mean scores were then calculated in percentage points, followed by the normalized gain (N-

Gain) to determine the extent of competency improvement. The results of this analysis are presented in Table 4.

Table 4. Changes in Partners Technical Competencies

Competency	Pre-intervention (%)	Post-intervention (%)	Δ (percentage points)	Normalized gain	Descriptive interpretation
Pump and PV panel assembly	30	85	+55	0.79	High improvement at the indicator level
Pump and PV panel maintenance	10	90	+80	0.89	High improvement at the indicator level
System operation	15	95	+80	0.94	High improvement at the indicator level

As shown in Table 4 and Figure 2, the three indicators showed substantial improvements at the group level. Assembly competency increased by 55 percentage points, while maintenance and system operation competencies each increased by 80 percentage points. The mean score across the three competencies with available baseline data increased from 18.3% to 90.0%, representing an overall improvement of 71.7 percentage points. The normalized gain values ranged from 0.79 to 0.94, all in the high category ($g \geq 0.70$). These values represent a descriptive analysis at the indicator level; in the absence of individual-level data, the findings should not be interpreted as evidence of statistical significance for the participant population.

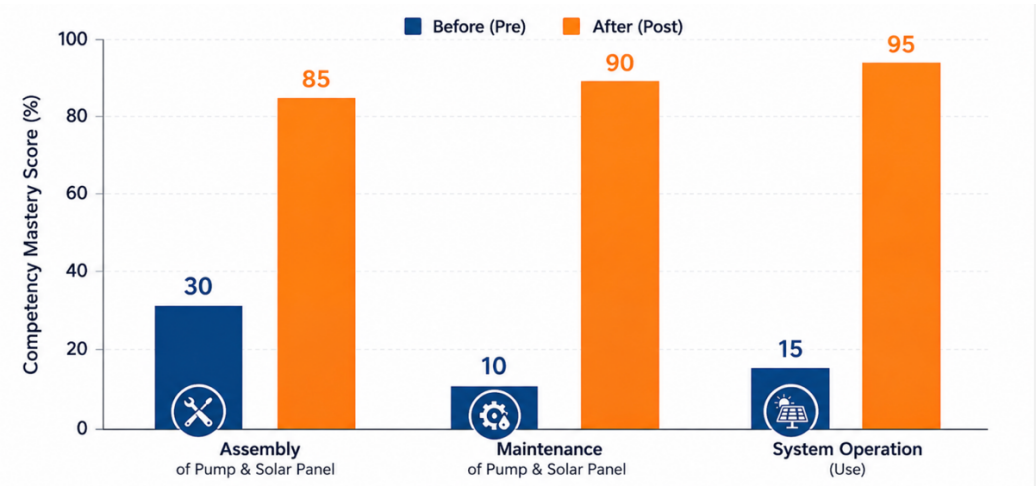


Figure 2. Pre- and post-intervention comparison of the three competencies with available baseline data.

The observed improvement pattern is consistent with the importance of practice-based learning. In another community engagement program, Syahid et al. (2024) reported improvements in renewable energy understanding and assembly knowledge following socialization and training activities. Hamdani et al. (2024) also incorporated education as an integral component of implementing alternative-energy water pumping systems. In the context of Bune Village, the greatest improvements in maintenance and system operation are particularly relevant because these two competencies determine the group's ability to sustain system operation after the community engagement team is no longer present intensively.

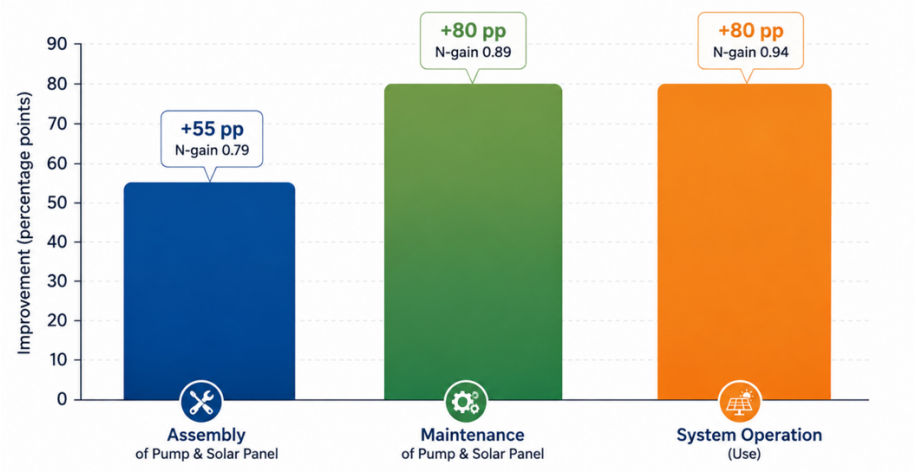


Figure 3. Percentage-point improvement and normalized gain for each competency indicator.

Technology literacy and management understanding were reported to reach 100% in the final evaluation. This finding indicates that all endline indicators assessed by the program team reached the targeted level of mastery; however, this study did not calculate the improvement because comparable numerical baseline data were unavailable. Distinguishing between final achievement and gain is necessary to avoid overstating the available evidence.

Technology Implementation and Technical Verification

The installed system consisted of two 250 W photovoltaic (PV) modules (500 W nominal in total) and a 400 W AC submersible pump with a 2 × 12 V, 120 Ah energy storage (Table 1). These specifications should be interpreted as component data rather than evidence that the system achieved its nominal operating point. From a simple power-balance perspective, the 500 W nominal PV capacity exceeds the 400 W nominal pump power by 100 W (25%); however, this margin is reduced by losses in the controller/inverter, variations in irradiance and temperature, and battery charging, so it does not by itself confirm that the pump operates at its rated point. Because data on the series-parallel configuration, solar irradiance, pump performance curve, total dynamic head, and conversion efficiency were unavailable, this study does not calculate overall system efficiency or make a definitive assessment of system sizing.

Indonesian literature indicates that solar-powered pumping performance is highly dependent on system configuration. Sinaga et al. (2021), for example, used a total PV capacity of 200 Wp to power a 60 W DC pump and reported a flow rate of 29 L/min at a 4 m head. Supriyono et al. (2024) reported a capacity of 30 L/min under a different system configuration, whereas Sudarmaji et al. (2025) employed a PV array of up to 10,000 Wp to operate two 3 HP submersible pumps at greater elevation and service distances. These comparisons are not intended to indicate that one configuration is superior to another; rather, they emphasize that PV capacity, pump power, pumping head, and required flow rate should be assessed as an integrated system.

The minimum flow-rate target of 50 L/min specified for the Bune Village intervention is equivalent to approximately 0.833 L/s. This target can be verified using the volume–time method at the outlet or by using a flow meter. For example, if a 20 L container is filled in 24 seconds, the flow rate is calculated as 20/24 = 0.833 L/s, equivalent to approximately 50 L/min. This example illustrates the measurement procedure only and does not represent an actual field result. Because actual flow-rate logs were unavailable, this study does not claim that the 50 L/min target was achieved.

Implications for Energy, Irrigation, and Productivity

The transition from fuel-powered pumping to photovoltaic (PV) energy has the potential to reduce variable operating costs and dependence on fossil fuels. Wardana et al. (2023) demonstrated the use of solar-powered pumping as an alternative to diesel-powered pumping for rice-field irrigation, while Yuniarti et al. (2025) reported reduced dependence on grid electricity through the

utilization of PV systems in hydroponic farming. However, the magnitude of potential cost savings depends on the initial investment, operating hours, component capacity, maintenance requirements, and the amount of energy actually displaced by the PV system.

In the Bune Village intervention, the target of up to 100% fuel reduction can only be stated for the pumping function within the intervention area if operational logs demonstrate that no fuel was subsequently used for the same function. This target should not be interpreted as indicating complete energy independence of the farmer group. Verification of actual fuel savings should include records of fuel consumption before and after implementation, fuel prices, operating hours, service area, and, where possible, the electrical energy generated by the PV system.

Improved water availability could theoretically support higher agricultural productivity; however, this study does not claim an increase in crop yield because data on cultivated area, crop variety, growing season, agricultural inputs, grain yield, and pre- and post-intervention weather conditions were unavailable. Claims regarding productivity improvements would be justified only after monitoring has been conducted for at least one cropping season. At the current stage, the outcome supported by quantitative evidence is the improvement in operators' technical competencies.

Sustainability and Asset Management

The sustainability mechanisms applied in the program were technical and institutional. Technically, SOPs covering start/stop procedures, inspection of the PV panels, cables, electrical connections, and piping, cleaning, and basic troubleshooting were introduced during training and subsequently applied by the trained operators during the mentoring phase.

Table 4. Summary of Outcomes, Claim Boundaries, and Verification Needs

Aspect	Outcome/Data	Defensible Claim	Further Requirement
Assembly competency	30% → 85%	Increased by 55 points; N_{gain} 0.79	Maintain troubleshooting practice
Maintenance competency	10% → 90%	Increased by 80 points; N_{gain} 0.89	Audit SOP compliance
System operation competency	15% → 95%	Increased by 80 points; N_{gain} 0.94	Evaluate operational consistency
Technology literacy/ management	Endline: 100%	Final achievement: 100%	Add a comparable baseline
Flow-rate performance	Target ≥50 L/min	Cannot yet be claimed as an outcome	Measure actual flow rate and head
Fuel consumption reduction	Target up to 100%	Cannot yet be claimed as an actual outcome	Record fuel use, operating hours, and service area
Agricultural productivity	No yield data available	Increase cannot yet be claimed	Monitor for at least one cropping season

Field observation verified that operators routinely performed pre-operation panel cleaning, checked electrical connection tightness, and executed system start-stop steps in accordance with the SOP checklists. Institutionally, task allocation was discussed during training, initial roles were assigned among group members, and an operational logbook was introduced to record operating hours and system faults, with active compliance confirmed through preliminary log entries recorded during routine monitoring visits. Similar practices involving operational and maintenance training have been reported by Supriyono et al. (2024), while Sa'adah et al. (2024) demonstrated the benefits of integrating technology with parameter monitoring to strengthen system management capacity. The following elements are recommendations for future development and are not reported as results of this program: designating an equipment coordinator, an operating schedule, and a reporting

mechanism, and allocating a portion of the savings from reduced energy expenditure to a dedicated maintenance fund (economic sustainability).

As a recommendation for future development, the logbook should be extended to record the date, start and end times, weather conditions, PV panel status, pump status, measured flow rate, service area, system faults, corrective actions, operator identity, and comparative fuel consumption. With records maintained for at least one cropping season, the program team and farmer group can move from functionality-based evaluation toward benefit-based evaluation, covering operating hours, flow rate, service area, cropping frequency, agricultural yield, energy costs, downtime, and maintenance expenditures.

CONCLUSIONS

The implementation of a solar-powered irrigation pump for the Rumpuleng Farmer Group in Bune Village was conducted through a participatory technology transfer approach integrating equipment provision, technical training, system installation, standard operating procedures (SOPs), and mentoring. Based on the pre-test and post-test scores of 16 participants, group-level competency increased from 30% to 85% for assembly, from 10% to 90% for maintenance, and from 15% to 95% for operation (mean 18.3% to 90.0%; normalized gain 0.79–0.94). Technology literacy and management understanding reached 100% at endline, but the improvement could not be calculated without a comparable baseline. These competency gains are explicitly descriptive; given the one-group design and the absence of individual-level data, they describe observed group-level changes rather than establishing a causal intervention effect.

The installed system comprised two 250 W PV modules and a 400 W AC submersible pump. The 50 L/min flow-rate target and the fuel-consumption reduction target of up to 100% are not measured outcomes, and no claim is made about crop productivity. The main practical contribution at this stage is the improvement of operator competencies, together with a framework based on SOPs and a logbook for managing the technology. Future work should monitor flow rate, pumping head, fuel savings, maintenance costs, and agricultural outcomes over at least one cropping season.

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AUTHOR CONTRIBUTION STATEMENT

II Putra was responsible for compiling, curating, and validating the data against the results of field testing. Nurfuadah was responsible for translating the manuscript into English and ensuring linguistic consistency. IPR Irawan was responsible for manuscript formatting, journal submission, coordinating revisions, and managing the publication process through to publication. Muhammad Rasul installed the solar-powered irrigation pump system, coordinated field operations, and prepared the initial draft of the report. Diky Pratama conducted field testing of the system, collected primary field data, and documented the activities. All authors reviewed and approved the final manuscript.

AI DISCLOSURE STATEMENT

Artificial intelligence (AI) tools were not used in the research design, field data collection, experimental testing, data analysis, interpretation of results, or scientific decision-making. AI assistance was limited to developing the framework for the discussion subtopics and providing linguistic editing of the manuscript. The authors independently verified all scientific content, data, interpretations, and conclusions and take full responsibility for the final publication.

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