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Empowering Rural Communities through Solar-Powered Irrigation Using a DC Pump for Sustainable Agriculture

Muhammad Hasim S. [1*], Akmal Hidayat [2], Hamidah Hamris [3], Ummul Mansir [4], Aminuddin [5], Mudarris [6], Iris Sumariyanto [7]

[1,2,3,5,6,7] *Universitas Negeri Makassar, Indonesia*

[4] *Politeknik Pertanian Negeri Pangkajene Kepulauan, Indonesia*

Corresponding e-mail: hasimapache@unm.ac.id

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ABSTRACT

Tondongkura Village has considerable potential for peanut farming but faces irrigation constraints due to hilly topography and dependence on gasoline-powered pumps. This community engagement program aimed to empower peanut farmers through a solar-powered irrigation system based on a DC pump as an appropriate technology for sustainable agriculture. A participatory approach was implemented through five stages: problem identification, system design, technology implementation, training and technology transfer, and mentoring and monitoring. The program involved 21 peanut farmers from the Bujung-Bujung Farmers Group. The results showed an increase in the average evaluation score from 36.3% to 72.1%, representing an improvement of 35.7 percentage points. The implementation strengthened farmers' knowledge, skills, and independence in operating and maintaining the irrigation system while reducing dependence on fossil-fuel-based pumping. The program demonstrates the potential of solar-powered irrigation as an appropriate technology to support more efficient, energy-independent, and sustainable peanut farming.

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INTRODUCTION

Tondongkura Village is one of the villages in Tondong Tallasa District, Pangkajene and Islands Regency, characterized by a mountainous landscape and a predominantly agricultural livelihood. Geographically, Tondongkura Village covers an area of 19.00 km^2, equivalent to 17.09% of the total area of the district, indicating considerable potential for agricultural development (Rasjid, 2025; Nurwahidah, 2025). The village has a population of 1,978 inhabitants, providing a relatively large productive workforce to support agricultural activities. However, the educational attainment of the community remains predominantly at the elementary education level, with approximately 39% of the population having completed only primary education or not completed primary school (Rasjid, 2025; Tondongkura, 2023). This condition highlights the importance of strengthening community capacity, particularly in the adoption and utilization of appropriate agricultural technologies.

Peanut cultivation is one of the main sources of household income in Tondongkura Village. However, peanut production remains subject to fluctuations due to conventional farming practices and strong dependence on weather conditions, particularly the availability of irrigation water (Sahri et al., 2022; Salsabila et al., 2026). Based on discussions with the Head of Tondongkura Village, Muhammad Ikhlas, S.Pd., and the Chairperson of the Bujung-Bujung Farmers Group in Bonto Tinggi Hamlet, the availability and distribution of irrigation water constitute one of the main constraints faced by peanut farmers.

The Bujung-Bujung Farmers Group manages approximately 3–5 hectares of peanut cultivation land. However, only approximately 30% of the agricultural land can be optimally irrigated during the planting season (April–October). Peanut plants require a relatively stable water supply, particularly during the flowering stage at approximately 25–35 days after planting. Although water is relatively abundant in the Baruttung River located in the valley, the mountainous and hilly topography creates difficulties in distributing water to agricultural fields located at higher elevations. Consequently, farmers remain highly dependent on rainfall, particularly during periods of limited precipitation, which restricts the optimal utilization of their cultivated land.

To overcome the lack of irrigation water, farmers continue to rely on conventional gasoline-powered pumps. The operation of these pumps can cost approximately IDR 1.2 million per month per hectare. In addition to the relatively high operating costs, access to subsidized fuel requires administrative requirements such as vehicle registration documents (STNK) and barcode registration, which can further constrain farmers' access to irrigation energy. These conditions indicate that the existing irrigation practice is not yet sufficiently efficient, affordable, or sustainable for smallholder farmers.

The irrigation problem is particularly important because adequate water availability is closely associated with crop growth and production. Previous studies have identified limited irrigation water as one of the important challenges in peanut cultivation, particularly during critical periods of plant growth (Nurzal et al., 2026; Rani et al., 2025). Therefore, improving irrigation access is not merely a matter of providing water but also involves developing an irrigation technology that is appropriate to the geographical, economic, and technological conditions of rural farming communities.

Tondongkura Village is also a village under the community development program of Universitas Negeri Makassar (UNM), providing an important context for strengthening community capacity through appropriate technology. Nevertheless, farmers' mastery of agricultural technology remains limited, particularly in the utilization of alternative energy sources and efficient water-management systems. This limitation reduces their ability to independently manage irrigation and increases their dependence on conventional fossil-fuel-based pumping systems. Accordingly, community empowerment needs to be directed toward strengthening farmers' practical knowledge and skills in adopting, operating, and maintaining appropriate irrigation technology.

One promising alternative is the utilization of solar energy to operate a DC water pump for agricultural irrigation. Solar-powered irrigation systems can provide an alternative to fossil-fuel-based pumping by utilizing renewable energy to supply irrigation water. In rural areas, such systems are particularly relevant where agricultural land is located far from conventional energy infrastructure or where the operational cost of fuel-powered pumps places a financial burden on farmers. The application of solar-powered irrigation can therefore contribute to more efficient water distribution while reducing farmers' dependence on fossil fuels.

However, the availability of solar-powered irrigation technology alone does not automatically ensure its sustainable utilization by farming communities. Technology adoption also requires farmers to possess adequate knowledge and practical skills to operate, maintain, and manage the system according to their agricultural needs. Thus, an effective intervention should integrate the provision of appropriate technology with community empowerment through training, technology transfer, and practical assistance. Such an approach can strengthen farmers' technological independence and increase the likelihood of sustained utilization of the irrigation system.

Based on the conditions described above, there is a gap between the availability of water resources in Tondongkura Village and farmers' ability to access and distribute that water efficiently to agricultural land. Although the Baruttung River provides a potential water source, the hilly terrain, high operating costs of gasoline-powered pumps, and farmers' limited access to alternative irrigation technologies prevent the optimal utilization of available water resources. At the same time, farmers' limited technological capacity remains a barrier to the adoption and sustainable management of renewable-energy-based irrigation systems. Therefore, an intervention that combines solar-powered irrigation technology with community capacity building is needed.

Accordingly, this community empowerment program aims to implement a solar-powered irrigation system using a DC pump as an appropriate technology for peanut farmers in Tondongkura Village. The program focuses on improving access to irrigation water, reducing dependence on gasoline-powered pumps, and strengthening farmers' capacity to operate and maintain renewable-energy-based irrigation technology. Through the integration of technology implementation, training, technology transfer, and assistance, the program is expected to support more efficient and sustainable irrigation practices and contribute to the development of sustainable peanut farming in Tondongkura Village.

METHOD

Identification and Analysis of Partner Problems

The first stage was conducted to obtain an overview of the actual conditions of the peanut farming areas and the irrigation problems encountered by the community partners. Data collection was carried out through field observations, interviews with farmers, group discussions, and measurements of site-specific technical conditions (Anang & Cipani, 2022). The identification process covered land area and characteristics, peanut cultivation practices, available water sources, the distance between water sources and agricultural fields, elevation or total pumping head, existing irrigation infrastructure, crop water requirements, and the availability of energy sources for pump operation.

In addition to technical aspects, the economic and operational constraints experienced by farmers were also identified, including electricity or fuel costs, limited access to energy sources, difficulties in obtaining water during certain periods, and farmers' capacity to operate agricultural technologies. The results of this assessment were used to determine the required water flow rate, pump capacity, power requirements, solar panel capacity, and water distribution network configuration appropriate to the field conditions and the partners' capacity (Sitepu et al., 2026).

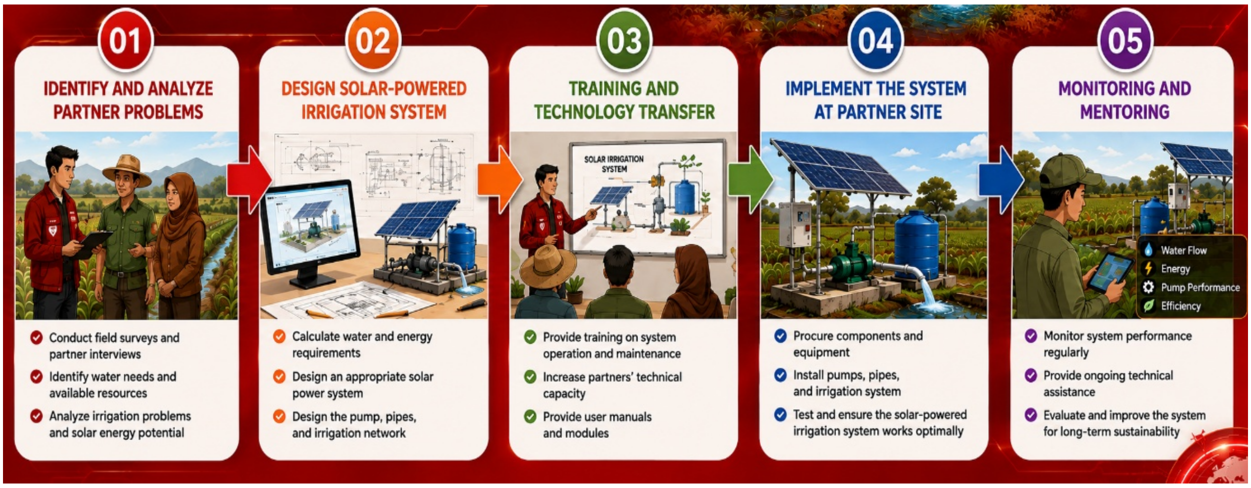

Figure 1. The five stages of the implementation method

Solar-Powered Irrigation System Design

Based on the results of the problem identification and needs assessment, a solar-powered irrigation system was designed according to the characteristics of the peanut farming area. The design considered crop water requirements, cultivated area, characteristics of the water source, distribution distance, pumping head, and solar radiation intensity at the site.

The system was designed by integrating photovoltaic (PV) panels, a DC water pump, a system controller, piping networks, and water distribution devices. Where required based on the energy assessment and operating pattern, the system could also be equipped with a battery or water storage facility to maintain the continuity of water supply.

Conceptually, the system operates by converting solar energy into electrical energy through PV panels to power the DC pump. Water from the available source is subsequently pumped into the distribution network and delivered to the peanut cultivation area. The design also considered energy efficiency, ease of operation, safety, component availability, investment and operational costs, and ease of maintenance by farmers.

The solar-powered irrigation system consists of four photovoltaic (PV) panels rated at 550 Wp each, with a total installed capacity of 2,200 WP (2.2 kWp) as the energy source, a 2 HP stainless-steel submersible pump for lifting and delivering water from the source, a 40 A MPPT controller for optimizing the utilization of energy generated by the PV panels, and a 2-inch-diameter piping network for distributing water to the partners' agricultural fields.

Training and Technology Transfer

Training was conducted after the system had been installed and confirmed to be fully operational. The training adopted a learning-by-doing approach, enabling farmers to gain direct experience in operating the technology. The training materials covered solar energy, the operating principles of solar-powered irrigation systems, PV panel functions, DC pump operation, system operation, water distribution management, and electrical safety procedures. The training was conducted at the Tondongkura Village Office and the agricultural field.

Farmers were also trained in solar panel maintenance, pump inspection, pipeline checking, component cleaning, connection inspection, and identification of basic technical faults. To assess the effectiveness of the technology transfer, farmers' knowledge was evaluated through pre-test and post-test assessments, while practical skills were evaluated by observing the partners' ability to independently operate the irrigation system.

System Implementation at the Partner Site

The implementation stage involved installing the solar-powered irrigation system in the partners' peanut farming area. The activities were conducted collaboratively by the community engagement team and the farmers, allowing the partners to participate directly in the installation process and understand the function of each system component.

The implementation included installing the solar panels at a location with optimal solar exposure, installing the DC pump at the water source, installing the piping network, and installing water distribution devices throughout the agricultural area.

After all components had been installed, an initial system test was conducted to ensure proper operation. The testing included verification of the solar panel power output, DC pump operation, resulting water flow rate, water distribution performance, and the condition of pipeline connections and the overall piping network. If any discrepancy was identified between system performance and field requirements, adjustments were made to the system configuration before the technology was routinely operated by the partners.

Mentoring and Monitoring

Mentoring was conducted after the irrigation system began to be used by farmers in peanut cultivation activities. The mentoring process aimed to ensure the sustainable utilization of the technology and to strengthen the partners' ability to independently address basic operational problems.

Monitoring was conducted through field observations, interviews with farmers, component inspections, and system performance records. The monitored parameters included the condition of the solar panels, DC pump performance, water flow rate, continuity of water distribution, condition of the piping network, and farmers' ability to operate and maintain the system, Monitoring also focused on assessing the benefits of the technology for agricultural activities, particularly its contribution to improving irrigation water availability, reducing dependence on conventional energy sources, and facilitating water supply for peanut crops.

The monitoring results were used as a basis for technical improvements and further strengthening of farmers' capacity. In the final stage, the partners were encouraged to establish an independent mechanism for managing and maintaining the system to ensure that the implemented technology could be utilized over the long term.

RESULTS AND DISCUSSION

Identification and Analysis of Partner Problems

Field identification revealed that the peanut farmer group in Tondongkura faces a major challenge related to limited irrigation availability during the planting season, particularly during periods of low rainfall. Based on field observations and interviews with the partners, only approximately 30% of the agricultural land could be optimally irrigated during the planting season. This condition is further exacerbated by the location of the main water source, the Baruttung River, which is situated in a valley, while the partners' agricultural fields are located at higher elevations with hilly terrain.

Consequently, farmers remain highly dependent on rainfall to meet the water requirements of peanut crops. When additional irrigation is required, farmers use conventional gasoline-powered pumps. The use of these pumps results in relatively high operating costs, reaching approximately IDR 1.2 million per month per hectare. In addition to operational costs, dependence on fossil fuels creates difficulties in accessing subsidized fuel due to certain administrative requirements.

The identification results also indicated that the partners' capacity to utilize renewable-energy technology for agricultural activities remains limited. Most partners had no previous experience operating solar-powered pumping systems, including limited understanding of photovoltaic (PV) panels, DC pumps, water distribution systems, and component maintenance. These findings indicate that the partners' challenges are not limited to inadequate irrigation infrastructure but also involve limitations in knowledge and skills related to the utilization of appropriate technology.

Based on these findings, the primary needs of the partners were directed toward the provision of an irrigation system capable of utilizing local water resources with lower energy costs and that could be independently operated and maintained by farmers. This condition provided the basis for developing a solar-powered irrigation system based on a DC pump as an appropriate technological solution.

Engineering and Design of the Solar-Powered Irrigation System

Based on the analysis of field conditions, the irrigation system was designed by considering the characteristics of the agricultural land, the location of the water source, topographical conditions, peanut crop irrigation requirements, and the solar energy potential at the partner site. The system consisted of photovoltaic (PV) panels as the energy source, a DC water pump as the driving unit, a control device, and a piping network for distributing water to the agricultural fields.

The system engineering was directed toward developing a configuration that was simple, easy to operate, and easy for farmers to maintain. The use of a DC pump enables electrical energy generated by the PV panels to be directly utilized to operate the pump, thereby reducing dependence on fossil fuels.

The design results indicated that integrating solar energy with a water pumping system has the potential to address two major challenges simultaneously: limited access to irrigation water and high operating costs associated with gasoline-powered pumps. Furthermore, the utilization of solar energy provides an opportunity for partners to exploit a locally available and renewable energy resource in the rural agricultural environment.

Training and Technology Transfer to the Partners

Training and technology transfer were provided to the partner group, consisting of 21 peanut farmers, beginning with seminar- and extension-based educational sessions conducted at the Tondongkura Village Office. The seminar aimed to provide the partners with a conceptual understanding of the importance of renewable energy utilization in supporting sustainable agricultural systems, particularly the application of a solar-powered irrigation system based on a DC pump.

Figure 2. Presentation of the Material and Introduction to Renewable Energy

Following the presentation of the materials, the activity continued with demonstrations and hands-on practice using a learning-by-doing approach, enabling the partners not only to acquire theoretical knowledge but also to gain practical experience in operating the implemented technology (Ulma et al., 2025). The practical activities included operating the irrigation system, regulating water distribution, inspecting the solar panels, DC pump, piping network and connections, as well as identifying basic technical faults.

Figure 3. Demonstration and hands-on practice

The training results indicated an improvement in the partners' understanding of solar-powered irrigation technology. Farmers who had previously been unfamiliar with solar-powered pumping systems began to understand the functions of the main components, operating principles, and procedures for system operation and maintenance. To further substantiate these results, the partners' knowledge was evaluated by comparing pre-test and post-test results, while practical skills were assessed through observations of their ability to operate the system, inspect component conditions, and perform basic maintenance procedures.

System Implementation at the Partner Site

Implementation involved the installation of the solar-powered irrigation system at the partners' agricultural site. The installation process actively involved the partners, including the selection of the solar panel location, installation of the DC pump, installation of the piping network, and configuration of water distribution to the agricultural area.

Figure 4.
a). Panel frame assembly process
b). Solar panel assembly and installation process

The direct involvement of the partners throughout the implementation process was an important component of the community empowerment strategy. Farmers were not merely recipients of the technology but also gained hands-on experience in understanding the functions and operational relationships among the system components. Following installation, system testing was conducted to ensure that the pump operated properly and that water could be distributed to the agricultural fields. The testing involved monitoring solar panel output, DC pump response, water flow rate, flow continuity, and the condition of the piping network.

The implementation results demonstrated that the solar-powered irrigation system could serve as an alternative water supply system for the partners' agricultural fields. The system also provided an alternative to gasoline-powered pumps, particularly when additional irrigation was required during the planting season.

Figure 5.
a). Activation process for the electrical power source
b). The DC pump is already running

The irrigation system uses a 2-inch-diameter pipe as the main water distribution channel, with a flow rate of approximately 350–500 liters per minute, depending on the intensity of solar radiation. The system is capable of pumping water to an elevation of up to 17 meters and distributing it over a distance of 200 meters from the water source to the agricultural fields, thereby supporting more effective water supply to cultivated areas located at higher elevations and relatively far from the water source.

Mentoring and Monitoring

Mentoring was conducted after the system was put into operation by the partners for peanut cultivation. The activity aimed to ensure the sustainable operation of the system while strengthening farmers' independence in managing the technology. Monitoring was conducted by observing the condition of the solar panels, DC pump, piping network, water distribution, and the partners' ability to operate and maintain the system. In addition to technical aspects, monitoring also assessed the benefits of the system for agricultural activities, particularly its ability to provide water during periods of insufficient rainfall.

The mentoring results indicated that farmers' direct involvement in operating and maintaining the system was an important factor in ensuring technology sustainability. Through the mentoring process, the partners not only obtained a solution to their irrigation constraints but also developed the ability to conduct basic inspections and address simple technical problems without being fully dependent on the community engagement team.

Impact of Technology Implementation on the Partners

The implementation of the DC pump-based solar-powered irrigation system generated impacts in terms of technical performance, economic potential, and community empowerment. From a technical perspective, the technology provided an alternative irrigation system that utilized solar energy to transport water from the source to the agricultural fields. This was particularly relevant for farmers because although water resources were available, their distribution was constrained by the local topographical conditions.

From an economic perspective, the use of solar energy has the potential to reduce operational costs previously incurred for pump fuel. However, the magnitude of the cost savings needs to be calculated based on pump utilization data before and after technology implementation so that the economic impact can be expressed quantitatively.

From an empowerment perspective, the program strengthened the partners' capacity to understand, operate, and maintain renewable-energy-based technology. With 21 community partners, the training and mentoring activities could be conducted intensively, allowing direct interaction between the community engagement team and farmers.

Overall, the implementation of the DC pump-based solar-powered irrigation system demonstrates that appropriate technology adapted to local conditions can serve as an effective instrument for community empowerment. The integration of irrigation problem-solving, renewable energy utilization, and farmer capacity building provides a foundation for developing a more efficient, energy-independent, and sustainable peanut farming system.

Table 1. Comparison of Pre-Test and Post-Test Results of 21 Community Partners

No	Evaluation Aspect	Pre-Test (%)	Post-Test (%)	Increase (%)
1	Understanding of Solar-Powered Irrigation Systems	38	82	44
2	Understanding of Solar Panel Components	40	86	46
3	Understanding of DC Pump Working Principles	34	62	28
4	Ability to Operate Irrigation Systems	36	70	34
5	Ability to Manage Water Distribution	33	65	32
6	Ability to Perform System Maintenance	33	74	41
7	Ability to Identify Malfunctions	35	68	33
8	Understanding of Solar Energy Efficiency	38	70	32
9	Self-Reliance in Technology Utilization	40	72	32
	Average	36,3 %	72,1 %	35,7 %

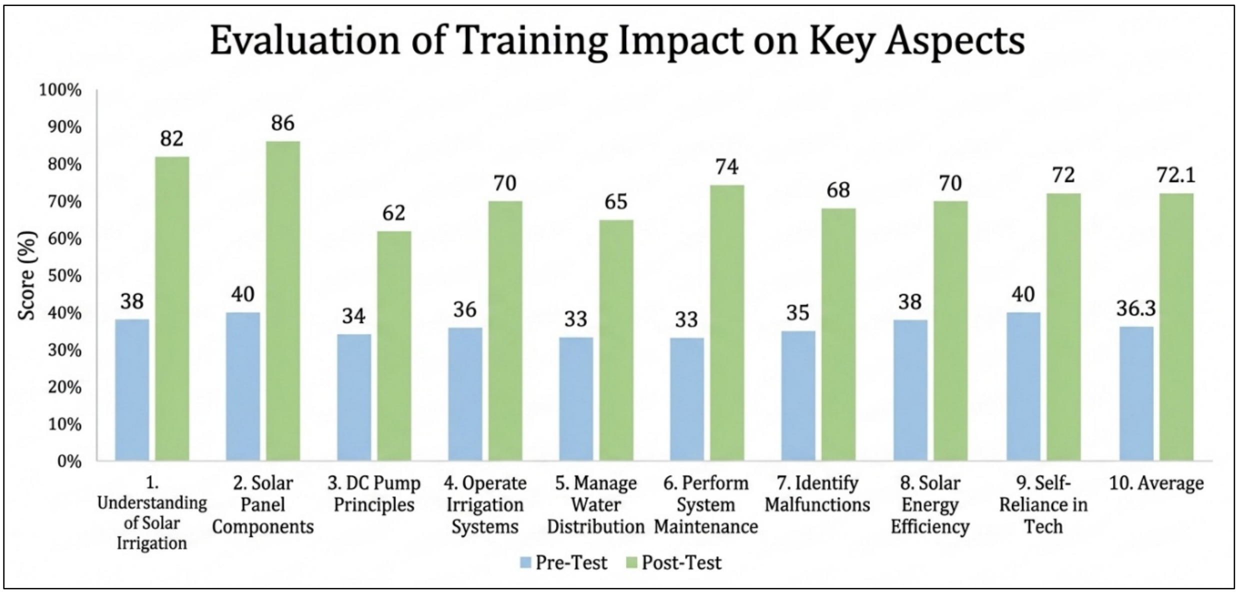

Figure 6. Evaluation aspect chart

The table and graph illustrate the pre-test and post-test evaluation results of training participants across nine distinct aspects regarding solar-powered irrigation technology, including the overall average score.

Key Findings and Data Summary

- Overall Impact: The overall average score increased significantly from 36.3% in the pre-test to 72.1% in the post-test, reflecting an overall gain of 35.7%.
- Highest Knowledge Gain:
- Understanding of Solar Panel Components achieved the highest post-test score at 86% and the largest increase of 46% (rising from 40%).
- Understanding of Solar-Powered Irrigation Systems recorded the second-highest gain, increasing by 44% (from 38% to 82%).
- Skills **and Operational Growth:**
- Ability to Perform System Maintenance showed substantial improvement, rising by 41% (from 33% to 74%).

- Ability to Operate Irrigation Systems saw a 34% increase, reaching 70% from a 36% baseline.

▪ **Lowest Increases:**

- Understanding of DC Pump Working Principles experienced the smallest increase at 28% (from 34% to 62%).
- Ability to Manage Water Distribution, Understanding of Solar Energy Efficiency, and Self-Reliance in Technology Utilization each recorded a 32% increase.

Overall, the data demonstrates that the training program successfully enhanced participants' comprehension and practical capabilities across all evaluated metrics, with the most notable advancements occurring in system component knowledge and maintenance capability.

CONCLUSIONS

The implementation of solar-powered irrigation systems based on DC pumps as appropriate technology provided a relevant solution to the irrigation constraints faced by peanut farmers in Tondongkura. The system utilized solar energy to support water distribution from locally available water sources to agricultural land, thereby offering an alternative to conventional gasoline-powered pumps and reducing dependence on fossil-fuel-based energy. The implementation also involved farmers directly in installation, operation, and maintenance activities, strengthening their capacity to utilize and manage renewable-energy technology independently.

The empowerment process through seminar-based knowledge transfer, practical training using the learning by doing approach, and subsequent mentoring demonstrated a substantial improvement in partner capacity. Evaluation of the participants showed that the average score increased from 36.3% in the pre-test to 72.1% in the post-test, representing an improvement of 35.7 percentage points. The highest knowledge gains were observed in understanding solar panel components, which increased by 46 percentage points (from 40% to 86%), and understanding solar-powered irrigation systems, which rose by 44 percentage points (from 38% to 82%). These findings indicate that the integration of appropriate irrigation technology with knowledge and skills transfer can strengthen farmers' capacity to operate and maintain the system while supporting the development of a more efficient, energy-independent, and sustainable peanut farming system.

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AUTHOR CONTRIBUTION STATEMENT

All authors contributed to the conceptualization, implementation of the community engagement activities, data collection and analysis, technology implementation, and preparation and revision of the manuscript. The first author was responsible for coordinating the overall activities, developing the research concept, analyzing the results, and preparing and finalizing the manuscript. Authors 2–6 collectively contributed to the implementation of the community engagement activities, engineering and implementation of the solar-powered irrigation system based on a DC pump, data collection and processing, training and mentoring of the community partners, results analysis, activity documentation, and manuscript preparation and revision. All authors have read, provided input, revised, and approved the final version of the manuscript for publication.

AI DISCLOSURE STATEMENT

The authors declare that artificial intelligence (AI) platforms were used as supportive tools during the initial stages of developing the conceptual ideas, formulating the main concepts, developing the manuscript framework, and organizing the structure of the scientific article. AI tools were also used to a limited extent to assist with language editing, grammar improvement, clarity of expression, and manuscript readability. AI was not used to generate, manipulate, analyze, or interpret the research data, nor to determine the scientific results or conclusions. All scientific ideas, data, analyses, interpretations, results, and conclusions presented in this manuscript were reviewed, verified, and remain the full responsibility of the authors.

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