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Implementation Solar PV Integrated Smart Greenhouse Technology for Urban Hydroponic Production at KWT Dorang Cinta Surabaya

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Abstract: KWT Dorang Cinta, a community-based farming group in Surabaya, Indonesia, faced several operational challenges in managing its Deep Flow Technique (DFT) hydroponic system. These included intermittent monitoring of pH and total dissolved solids (TDS) using portable instruments, manual nutrient dosing and pH adjustment based on members' experience, and reliance on grid electricity to operate the water circulation pump. These limitations reportedly contributed to reduced crop yields and increased electricity costs, as indicated by interviews with group members. This community service program aimed to implement a solar photovoltaic (PV)-integrated smart greenhouse to improve hydroponic nutrient management and provide an alternative energy source for system operation. The intervention integrated pH, TDS, water-level, and temperature sensors with an ESP32-based controller, automated nutrient and pH dosing systems, smartphone-based monitoring, and a 300 Wp solar PV system equipped with a 12 V/100 Ah battery. The implementation process comprised field assessment, system development, installation, training, equipment handover, and evaluation. A five-point Likert-scale questionnaire was administered to 15 participants to assess their understanding, perceived usability, operational readiness, and perceived benefits of the training. The overall mean score was 3.97 out of 5, indicating generally positive participant perceptions. The highest rating was recorded for perceived productivity benefits (4.40 ± 0.51), whereas troubleshooting skills (3.33 ± 1.05) and knowledge of PV system operation (3.40 ± 1.12) received the lowest ratings. These findings demonstrate the technical feasibility of implementing the integrated system and its positive acceptance among participants. However, the relatively lower ratings for troubleshooting and PV operation underscore the need for continued technical mentoring and long-term performance evaluation to ensure effective system operation and sustainability.

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Introduction

Urban agriculture has become an important strategy for strengthening food security and promoting sustainable food production in densely populated cities. Rapid urbanization and limited agricultural land have increased the need for cultivation systems that can produce fresh vegetables within restricted spaces. Hydroponics offers a practical alternative by enabling plant cultivation without conventional agricultural soil and facilitating the use of compact urban areas for food production. Nevertheless, the sustainability of hydroponic

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cultivation depends on effective nutrient management, reliable electricity supply, and appropriate monitoring of growing conditions. Recent advances in smart hydroponics demonstrate the potential of integrating sensors, Internet of Things (IoT) technologies, and automated control to improve system monitoring and operational management (Wei En et al., 2026; Contemporary Smart Hydroponics Systems, 2025). These developments highlight the importance of selecting technologies that not only improve technical performance but also remain accessible and manageable for community-based urban farming groups with limited technical expertise.

The Women Farmers Group (Kelompok Wanita Tani, KWT) Dorang Cinta, located in Perak Barat, Surabaya, Indonesia, is a community-based urban agriculture group established in 2020. The group comprises 25 members and operates a 4 × 6 m greenhouse equipped with a Deep Flow Technique (DFT) hydroponic installation. Its cultivated vegetables include lettuce, pakcoy, caisim, spinach, and water spinach. Despite having established cultivation infrastructure, the group continues to face operational constraints that affect production consistency. An initial field assessment conducted by the community engagement team on 6 December 2025 identified two principal technical challenges: intermittent manual monitoring and adjustment of hydroponic nutrient solutions and dependence on grid electricity to operate the DFT circulation pump. Based on interviews with group members, these conditions contributed to reduced crop yields due to inconsistent nutrient management and high electricity costs associated with the continuous operation of the circulation pump. These challenges highlighted the need for technological improvements and practical capacity development to support more reliable, efficient, and sustainable hydroponic management.

The first challenge concerns the monitoring and control of nutrient-solution quality. Before the intervention, pH and total dissolved solids (TDS), expressed in parts per million (ppm), were measured intermittently using portable instruments. Nutrient solutions were prepared by manually adding AB Mix fertilizer and pH-adjustment solutions according to the members' experience and estimated quantities. This practice required members to perform repeated manual measurements and adjustments, while changes in nutrient concentration and acidity could remain undetected between measurement intervals. Consequently, maintaining consistent nutrient-solution conditions required additional attention and operational effort from group members. IoT-enabled greenhouse systems can integrate sensors, communication technologies, and control mechanisms to facilitate more frequent monitoring and timely operational responses (Hosny et al., 2025). Research on contemporary smart hydroponics similarly identifies sensor integration, automation, and system interoperability as important considerations in developing manageable hydroponic installations (Contemporary Smart Hydroponics Systems, 2025). For KWT Dorang Cinta, integrating pH, TDS, water-level, and temperature sensors with automated dosing components provides a practical approach to simplifying routine monitoring and nutrient management. The use of sensor-based monitoring and automated control is particularly relevant for community-based farming groups because it can reduce reliance on repeated manual measurements and support members in making operational decisions through accessible monitoring interfaces, following appropriate technical training.

A second challenge is the reliance of the existing DFT system on a continuous electricity supply. Since the circulation pump is essential for maintaining water and nutrient movement through the hydroponic installation, prolonged power interruptions can stop circulation and disrupt the delivery of water and nutrients to plant roots, potentially affecting growing conditions. Solar photovoltaic (PV) technology combined with battery storage offers

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an alternative energy source for supporting essential greenhouse equipment. Reviews of photovoltaic greenhouse systems have highlighted the potential for combining agricultural activities with renewable electricity generation, while emphasizing that system performance depends on solar availability, configuration, energy demand, and interactions between the energy system and cultivation environment (Hassanien et al., 2025). Furthermore, smart greenhouse research identifies renewable energy integration and energy-efficient operation as relevant approaches to improving the sustainability of controlled-environment agriculture (Soussi et al., 2025). For a small urban greenhouse managed by a community-based women's farming group, a relatively compact solar PV and battery system is a relevant option because it can utilize available rooftop or greenhouse space to support essential electrical loads without requiring major changes to the existing hydroponic infrastructure. The integration of a solar charge controller and battery storage also enables generated electricity to be stored for subsequent use, subject to the available generation capacity and equipment demand. From an operational perspective, this configuration provides an opportunity to reduce dependence on grid electricity and introduce renewable-energy technology through practical training and routine maintenance activities that can be learned by group members.

Previous research has examined smart hydroponic monitoring, IoT-based greenhouse management, and photovoltaic integration, while community engagement studies have demonstrated the importance of practical training when introducing technology to agricultural groups. For example, Herdiana et al. (2025) reported positive outcomes from a hands-on training program for farmers using smart irrigation technology in hydroponic farming. Such findings emphasize that technology deployment should be accompanied by activities that enable participants to understand, operate, and maintain the introduced systems. For non-expert users, the practical suitability of an integrated smart greenhouse depends not only on sensor accuracy and energy-generation capacity but also on operational simplicity, accessibility of monitoring information, basic troubleshooting skills, and the availability of technical assistance. The combination of IoT-based monitoring and solar PV is therefore relevant to KWT Dorang Cinta because it addresses two interconnected operational needs: simplifying routine hydroponic management and providing an alternative electricity source for essential equipment. By combining technology implementation with hands-on training and mentoring, the program seeks to ensure that the introduced system is compatible with the group's existing infrastructure and operational capabilities. In this context, the contribution of the present program lies in implementing these integrated components within an established urban women's farming group and evaluating participants' perceptions of the technology following practical training, including its usefulness, ease of operation, operational readiness, and training benefits.

Accordingly, this community service program aims to implement solar-PV-integrated smart greenhouse technology for urban hydroponic production at KWT Dorang Cinta, Surabaya, Indonesia. The intervention integrates sensors for monitoring pH, TDS, water level, and temperature with automated nutrient-control components and a solar PV system supported by battery storage. Practical training and mentoring are provided to familiarize participants with system operation, monitoring procedures, and basic troubleshooting. Program evaluation focuses on the implementation of the technology and participants' post-training perceptions of its usefulness, ease of operation, operational readiness, and perceived training benefits. Through this approach, the program provides practical evidence on the implementation and user-oriented evaluation of renewable-energy-supported smart hydroponic technology in a community-based urban agriculture setting.

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Method

The community service methodology adopted the standard PkM implementation stages, comprising socialization, training, mentoring, technology handover, and evaluation. These stages were preceded by an initial field assessment to identify the partner's needs and followed by hardware and software development, system integration, and on-site installation as part of the technology implementation process. This framework was selected to ensure that the introduced technology addressed the operational needs of KWT Dorang Cinta while enabling members to acquire the skills required to operate and maintain the system. Figure 1 illustrates the overall workflow of the community service program.

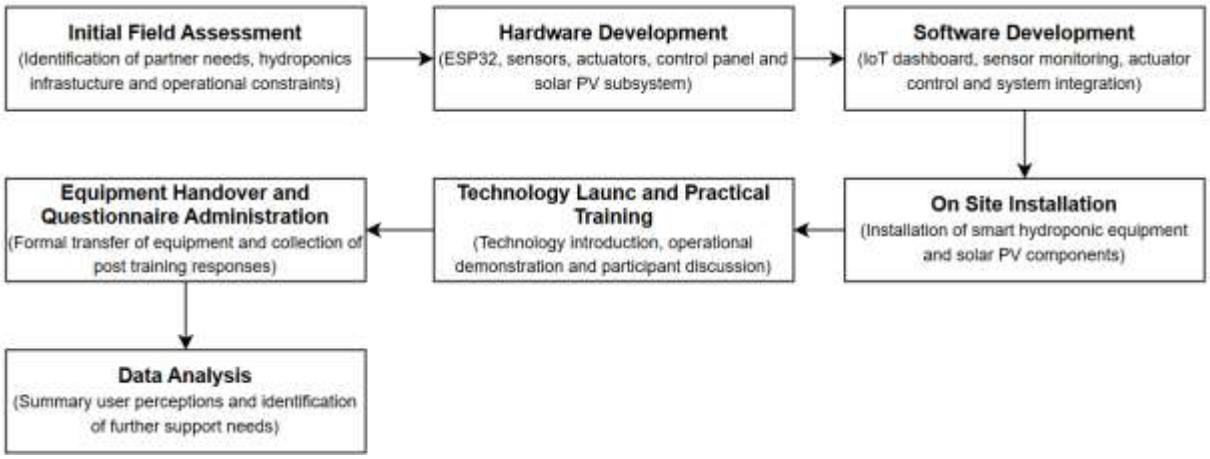


Figure 1. Workflow of Solar PV Integrated Smart Greenhouse Implementation

The program was implemented at Kelompok Wanita Tani (KWT) Dorang Cinta, located in Perak Barat, Surabaya, East Java, Indonesia. Established in 2020, the group comprises 25 members and manages an existing greenhouse measuring approximately 4 × 6 m. The greenhouse is equipped with a Deep Flow Technique (DFT) hydroponic installation used to cultivate lettuce, pakcoy, caisim, spinach, and water spinach. Urban and peri-urban agriculture can support access to fresh food and contribute to the resilience of urban food systems, although its sustainability depends on local resources, infrastructure, and management practices (Food and Agriculture Organization of the United Nations [FAO], n.d.; Schnitzler, 2013). In community-based cultivation, the suitability of an intervention therefore needs to be considered in relation to the existing facilities and the operating practices of the intended users.

An initial field assessment conducted by the community engagement team on 6 December 2025 identified two principal operational challenges at the existing hydroponic greenhouse facility, as shown in Figure 2. First, pH and total dissolved solids (TDS) were measured intermittently using portable instruments, while nutrient and pH-adjustment solutions were added manually according to members' experience. Second, the DFT circulation pump depended on the grid electricity supply. These findings informed the design of an intervention combining sensor-based monitoring, dosing components, IoT connectivity, and solar photovoltaic (PV) power. The use of connected sensors and control components is consistent with established approaches to IoT-based greenhouse management (Hosny et al., 2025; Ahmed et al., 2025).

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(a) Styrofoam Hydroponic Water Container (b) Non-Continous PPM and pH Measurements



(c) Manual Control of Hydroponic Solution pH and PPM Levels

Figure 2. Existing Hydroponic Greenhouse Facility at KWT Dorang Cinta, Perak Barat, Surabaya, Indonesia

Smart Greenhouse System Design

The intervention integrated three subsystems: (1) sensor-based monitoring and dosing, (2) IoT-based monitoring and control, and (3) solar PV generation with battery storage. The design follows the general architecture of smart hydroponic systems, in which sensors acquire cultivation data, a controller processes inputs, communication technologies transmit information, and actuators perform designated control functions (Ahmed et al., 2025).



Figure 3. Hardware Assembly and Soldering of The Electronic Components for the IoT Based Smart Hydroponic System

The hardware subsystem uses an ESP32 microcontroller as the central processing and communication unit. The sensor suite consists of DFRobot pH and TDS sensors, a DS18B20 water-temperature sensor, a float sensor for water-level detection, and an RTC DS3231 module. The actuators comprise a brushless water pump for circulation and peristaltic pumps for liquid dosing. MOSFET drivers and relay modules provide the switching interfaces between the controller and the actuators. The electronic components were assembled, soldered, and integrated into a control panel as shown in Figure 3, while the mechanical assembly and integration of the smart hydroponic installation are presented in Figure 4.

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Figure 4. Mechanical Assembly of the Smart Hydroponic Installation

The software subsystem provides a smartphone-accessible interface called *Smart Hidroponik*. The dashboard is designed to display pH, TDS, and water-temperature readings, visualize sensor data, indicate pump status, and provide dosing-control functions. It also presents information on dosing quantities and their usage. The software development process and smartphone dashboard are shown in Figure 5. MQTT is used for data communication in the reported implementation. Such connected monitoring and control architectures are widely discussed in research on IoT-enabled greenhouse systems and smart hydroponics (Hosny et al., 2025).



Figure 5. Software Development and Smartphone Dashboard of the Smart Hidroponik System

Sensor Integration and Solar PV Power Supply

Sensor monitoring and Actuator Integration

The pH and TDS sensors are used to monitor nutrient-solution characteristics, while the DS18B20 measures water temperature and the float sensor detects water level. These parameters provide complementary information for monitoring hydroponic operating conditions. Monitoring pH and dissolved nutrient concentration is particularly relevant because nutrient-solution management influences nutrient availability and the operation of hydroponic cultivation systems (Neocleous & Savvas, 2015; Hosny et al., 2025).

Sensor readings are acquired by the ESP32 and made available through the dashboard. The peristaltic pumps are assigned to dosing nutrient solutions A/B and pH-adjustment liquids, while the brushless pump supports circulation through the DFT installation. The RTC DS3231 provides time information for functions requiring a time reference. The intended operational sequence consists of sensor acquisition, controller processing, dashboard display, and actuator operation according to the configured control logic. Sensor monitoring and automated dosing are related but distinct functions: the availability of sensor readings does not, by itself, establish that dosing accuracy or nutrient stability has been validated. For this reason, any claims regarding measurement accuracy, control precision, or improved nutrient-use efficiency require specific test results rather than being inferred from the system configuration alone (Ahmed et al., 2025; Neocleous & Savvas, 2015).

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Solar Photovoltaic Integration

The energy subsystem comprises a 300 Wp solar PV panel, a 12 V/100 Ah valve-regulated lead-acid (VRLA) battery, and a 30 A solar charge controller (SCC), as shown in Figure 6. The subsystem was installed to provide an alternative electricity source for the connected greenhouse equipment. The solar panel converts incident solar radiation into electrical energy, while the charge controller manages charging and the battery stores energy for subsequent use. Integrating PV technology with greenhouse operations is a recognized approach to combining agricultural production and renewable electricity generation. However, actual performance depends on solar availability, panel characteristics, installation conditions, energy demand, and storage configuration (Hassanien et al., 2025; Yao et al., 2025). Battery storage can also influence greenhouse energy autonomy, making measured generation, demand, and storage performance important for evaluating the effectiveness of the system (Gholami et al., 2025). The present study reports the installed PV capacity and battery specifications as system characteristics. It does not quantify energy autonomy, electricity-bill reductions, or uninterrupted operation during grid outages because measurements of PV generation, battery state of charge, equipment consumption, and operating duration were not included in the reported post-training evaluation.



Figure 6. Assembly of the Solar Photovoltaic Power Supply Subsystem for The Smart Greenhouse

Questionnaire Instrument and Data Collection

Post-training evaluation was conducted using a structured questionnaire completed by 15 respondents. Ten production related statements were assessed on a five-point Likert scale, with scores ranging from 1 to 5. The statements addressed participants' perceptions of the technology's usefulness, ease of operation, understanding of monitoring and control functions, confidence in managing nutrient conditions, and readiness to operate the system.
Questionnaires using Likert-type response categories are commonly used to summarize attitudes and perceptions, although the nature of the response scale should be considered when selecting and interpreting descriptive statistics (Boone & Boone, 2012). In this study, the questionnaire was intended to describe the participants' views after they had been introduced to the technology. It was not designed as a controlled experiment and did not measure crop yield, nutrient consumption, electricity generation, or changes in operating costs.

Result and Discussion

One Site Installation

The integrated system was installed at KWT Dorang Cinta on 30 June 2026. The activities involved positioning the solar panel and its support structure, installing the control panel and dosing components, and integrating the equipment with the existing hydroponic installation. The on-site implementation was intended to introduce the monitoring and control system while retaining the partner's existing cultivation infrastructure. The installation records document the placement of the solar panel, control panel, and dosing assembly. These records were used to describe implementation activities, not to establish improvements in crop yield or energy performance. This distinction is important because the physical

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installation of smart monitoring and renewable-energy components does not automatically demonstrate their long-term operational effectiveness (Hassanien et al., 2025; Gholami et al., 2025).



Figure 7. On Site Installation of The Solar PV Panel, Support Structure, Control Panel, and Nutrient-Dosing Assembly.

Technology Launch and Practical Training

The technology launch and operational training were conducted on 2 July 2026 at the partner's site. Participants included members of KWT Dorang Cinta, the local village head, and a representative of the Surabaya Food Security and Agriculture Office (Dinas Ketahanan Pangan dan Pertanian, DKPP). The activity began with an explanation of the functions and expected benefits of the IoT-based smart hydroponic system integrated with solar photovoltaic (PV) technology. Participants were then introduced to the installed equipment, including the sensors, controller, solar PV components, and supporting devices. The implementation team demonstrated how to access the monitoring dashboard, read sensor information, check pump status, and understand the nutrient-dosing control interface.

The activity also encouraged direct interaction between the implementation team and the partner community. Participants were given opportunities to ask questions, express their views, and discuss how the introduced technology could support their existing hydroponic activities. Their involvement during the explanation and demonstration sessions provided an opportunity to relate the system's functions to their daily cultivation practices. One practical challenge addressed during the training was the need for participants to become familiar with the integrated monitoring and control functions, which differed from their previous practice of manually measuring nutrient-solution parameters and adjusting nutrient levels. To address this learning need, the implementation team provided step-by-step explanations, direct demonstrations of the dashboard and equipment functions, and opportunities for participants to clarify the operating procedures. This guided approach was intended to make the technology easier to understand and to support participants in becoming familiar with its basic operation.



Figure 8. Practical Demonstration of the Iot Based Smart Hydroponic System Integrated with Solar

The training was designed to introduce participants to the system's principal functions and provide initial exposure to its operation. Previous research on community training for

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smart irrigation in hydroponic farming supports the relevance of combining technical explanations with practical demonstrations when introducing agricultural technology (Herdiana et al., 2025).

Equipment Handover

Following the launch and training, the equipment was formally handed over to KWT Dorang Cinta on 2 July 2026 through a Berita Acara Serah Terima (BAST). The handover documented the transfer of responsibility for managing the installed technology to the community partner. It was witnessed by the local village head and members of the group.

Formal handover was treated as an implementation milestone because continued operation of community-based technology depends partly on the partner's role in equipment management and maintenance. Nevertheless, the signing of a handover record alone does not establish long-term adoption or sustained operational performance; these outcomes would require follow-up observations after the intervention (Salemink et al., 2017).



Figure 9. Formal Handover of the Smart Hydroponic Equipment to KWT Dorang Cinta Following the Signing Of The Handover Record

Post Training Questionnaire Results

Post-training perceptions were evaluated using ten questionnaire indicators completed by 15 respondents. The indicators covered perceived understanding of the technology, system operation, monitoring and parameter adjustment, photovoltaic operation, troubleshooting, training benefits, ease of application, and anticipated benefits for hydroponic cultivation. Table 1 presents the mean score, sample standard deviation (SD), and proportion of respondents assigning a score of 4 or 5 on the five-point scale.

Table 1. Post Training Questionnaire Results for the Smart hydroponic Greenhouse Implementation (n = 15)

No	Questionnaire Indicator	Mean ± SD	Score 4-5 (%)
1)	Understanding the function of the solar-PV-based smart hydroponic greenhouse	3.93 ± 0.70	86.7
2)	Ability to switch the smart greenhouse system on and off correctly	3.80 ± 0.86	80.0
3)	Ability to read pH, TDS, and water-level monitoring data	3.93 ± 0.88	86.7
4)	Ability to adjust pH and PPM parameters according to crop requirements	4.00 ± 0.76	86.7
5)	Ability to activate the PV system as an alternative to grid electricity	3.40 ± 1.12	60.0
6)	Ability to perform initial troubleshooting when a sensor or pump malfunctions	3.33 ± 1.05	60.0
7)	Perceived improvement in the ability to operate the smart greenhouse following training	4.33 ± 0.49	100.0
8)	Perceived ease of applying the technology in hydroponic cultivation	4.27 ± 0.59	93.3

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9)	Confidence that the technology can help maintain pH and nutrient stability	4.33 ± 0.49	100.0
10)	Confidence that the solar-PV-based smart greenhouse can improve hydroponic vegetable productivity	4.40 ± 0.51	100.0

Note: Scores range from 1 to 5. SD denotes sample standard deviation. Score 4–5 represents the proportion of respondents selecting either of the two highest response categories.

The questionnaire findings indicate generally positive post-training perceptions among the participants. The high rating for the technology's potential to improve hydroponic vegetable productivity attributed to the direct relevance of the introduced system to the challenges previously experienced by KWT Dorang Cinta. Improved monitoring of pH and nutrient concentrations, together with more consistent nutrient management, was perceived as beneficial for supporting plant growth and cultivation outcomes. These benefits were relatively easy for participants to understand because they were directly related to their daily hydroponic activities. In contrast, troubleshooting sensor or pump malfunctions and operating the solar PV system received comparatively lower ratings, accompanied by greater variation in participants' responses. During the evaluation, several participants expressed concerns about handling electrical components, particularly when dealing with equipment malfunctions and solar PV operation. This concern reduced their confidence in performing these tasks independently. Furthermore, as a community group consisting of adult women whose primary activities involve hydroponic cultivation, participants had to become familiar with digital monitoring devices and electrical systems that were additional to their existing farming practices. Therefore, further hands-on training, repeated demonstrations, clear electrical safety instructions, and supervised troubleshooting practice are necessary to strengthen their operational confidence and readiness.

Interpretation of Preceived Competence and Training Needs

The questionnaire results suggest that respondents viewed the technology positively and expressed confidence in its potential application to hydroponic cultivation. The relatively high scores for monitoring, parameter adjustment, and perceived training benefits indicate favorable initial acceptance of the system. However, these findings represent respondents' self-assessments rather than independently verified technical competence. The lower scores for troubleshooting and PV operation identify practical priorities for follow-up capacity-building activities. Further training should emphasize recognizing abnormal sensor readings, checking electrical and communication connections, responding to pump failures, and safely operating the PV power subsystem. Supervised troubleshooting exercises and repeated hands-on practice could be incorporated into subsequent mentoring sessions. Competence should then be evaluated through practical task completion, structured observation, or scenario-based tests rather than self-reported ratings alone. The difference between confidence in the technology's potential benefits and perceived readiness to address technical faults is particularly relevant. Although all respondents assigned a score of 4 or 5 to the anticipated productivity benefit, only 60.0% did so for troubleshooting and PV operation. This contrast indicates that positive expectations about the technology do not necessarily imply equivalent confidence in managing its technical requirements. Continued assistance is therefore important to support routine operation and maintenance after the equipment handover.

Discussion

Community Empowerment and Sustainability

The implementation of the solar-PV-integrated smart hydroponic greenhouse at KWT Dorang Cinta demonstrates the practical application of IoT-based monitoring, nutrient-dosing

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control, and renewable energy in community-based urban agriculture. The overall post-training questionnaire score of 3.97 out of 5 indicates generally positive participant perceptions of the technology. These findings align with previous studies highlighting the potential of smart hydroponics to support more informed cultivation management through sensor-based monitoring and automation (Ahmed et al., 2025). However, the lowest scores concerned troubleshooting sensor or pump malfunctions (3.33) and operating the PV system (3.40), indicating priorities for further practical training. Although respondents expressed confidence that the technology could improve vegetable productivity, actual improvements in yield and energy resilience have not yet been established. Follow-up mentoring, routine maintenance records, and quantitative monitoring of crop production and PV performance are therefore necessary to support sustainable adoption. As Herdiana et al. (2025) demonstrated in a related community-training context, evaluation methods should also be selected carefully to distinguish perceived benefits from measured learning outcomes. Overall, the program provides an initial foundation for community-based smart farming. Its long-term contribution will depend on strengthening participants' operational capabilities, verifying technical performance, and documenting agricultural outcomes over time.

Conclusion

This community engagement program successfully implemented a solar-PV-integrated smart greenhouse at KWT Dorang Cinta, Surabaya, by integrating IoT-based monitoring, automated nutrient and pH dosing, smartphone-accessible system supervision, and photovoltaic energy storage with the partner's existing DFT hydroponic infrastructure. The intervention addressed two practical constraints identified during the initial assessment: intermittent manual monitoring and adjustment of hydroponic nutrient conditions and dependence of the circulation system on grid electricity.

The post-training evaluation indicated generally positive participant perceptions, with an overall mean score of 3.97 out of 5. Participants reported particularly favorable perceptions regarding the usefulness of the training, ease of technology application, and the potential of the system to support hydroponic production. However, the comparatively lower scores for troubleshooting sensor or pump failures (3.33 ± 1.05) and PV-system operation (3.40 ± 1.12) indicate that technology deployment alone does not ensure sufficient operational readiness. Continued hands-on mentoring should therefore prioritize fault identification, basic electrical troubleshooting, sensor checking, pump maintenance, and safe operation of the PV subsystem. The main contribution of the program is the practical integration of smart hydroponic management and renewable-energy support within an existing community-based urban agriculture facility.

Recommendation

Following the implementation of the solar-PV-integrated smart greenhouse, several follow-up actions are recommended to ensure the sustainability and effective utilization of the introduced technology. KWT Dorang Cinta is encouraged to conduct routine monitoring of sensor readings, maintain the hydroponic equipment and solar PV components, and follow the established operating and safety procedures. Particular attention should be given to basic system checks while electrical troubleshooting and repairs should be performed with assistance from personnel with appropriate technical expertise. Relevant government agencies, particularly the Surabaya Food Security and Agriculture Office (DKPP), are encouraged to provide continued technical assistance, capacity-building programs, and

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support for the maintenance and potential development of the system. Future project teams should conduct periodic monitoring and mentoring, provide follow-up training on sensor and pump troubleshooting and solar PV operation, and evaluate system performance over a longer period, including its effects on hydroponic productivity, electricity consumption, and operational sustainability. These collaborative efforts are expected to strengthen the partner group's capacity to operate and maintain the technology while supporting the long-term sustainability of urban hydroponic farming.

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