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# Utilization of solar energy in hydroponic systems for enhancing energy independence in farming communities

[1]Lorenta In Haryanto, [2]Tri Yuni Hendrawati, [3]Darto Darto, [1]Febri Yani, [1]Firgi Adha Listanto, [1]Dimas Yoga Pradipta Pratama

*[1]Department of Agribusiness, Faculty of Agriculture, [2]Department of Chemical Engineering, Faculty of Engineering,*
*[3]Department of Management, Faculty of Economics and Business, Universitas Muhammadiyah Jakarta*
*Jl. K.H. Ahmad Dahlan, Cireundeu, Tangerang Selatan, Banten, 15419, Indonesia*

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**ABSTRACT**

Urban agriculture challenges, such as limited land and time constraints, make hydroponic technology ideal to support the development of sustainable agricultural systems. Water pumps are essential for distributing nutrient water to plants in a hydroponic system. Using solar panels as an alternative energy source for hydroponic water pumps reduces operational costs and supports energy conservation efforts. This project aims to implement solar panels on hydroponic water pump machines to create energy independence for farmer groups. The activities cooperated with a farmer group called Hidroponik Generik (HG) in Pesanggrahan from April to October 2024. The implementation method includes training and assistance in applying vertical hydroponic technology and training and assistance in solar power generation for hydroponic systems. Results from community service show that solar-powered pumps reduce electricity costs, enhance income potential, and support sustainable farming. An 800 WP solar panel provides 1600 WH daily, powering pumps for 12-13 hours, cutting electricity usage by 66 percent and reducing monthly expenses by 10 percent. Along with vertical hydroponic installation, this program increases farm income by 15 percent, with a 45 percent improvement in participants' understanding of solar technology. The results of the activities were deemed successful after the partners expressed satisfaction with the conducted activities.



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## 1. INTRODUCTION

The collaborator of this program is the Independent Agricultural and Rural Training Center (P4S) Hidroponik Generik (HG) situated on Jln. Manunggal 2, RT 03/RW 02, Petukangan Selatan Urban Village, Pesanggrahan District, Indonesia. This farmer group comprises 20 members, of whom 11 are active. P4S Hydroponics has fostered other farmers' groups located throughout the DKI Jakarta region. Hidroponik Generik was founded in 2016, formerly named Gang Hijau Asmat. The commodities are red and green spinach cultivated using hydroponic systems, specifically the Deep Flow Technique (DFT) and Nutrient Film Technique (NFT). The farmer groups possess a land area of 200 m² with a monthly production capacity of 600 kg. The production facilities comprise three DFT beds, including 1,021 planting holes, and five NFT beds, containing 6,000 planting holes. The production operates on a harvest of three circles of

✉ Corresponding Author: **Lorenta In Haryanto:** Tel. +62 21-7430689 | E-mail: lorenta@umj.ac.id

50 kg per week, with 20 kg of red spinach sourced from the garden and 30 kg of green spinach cultivated on the land of fostered farmers. The HG farmer group diversifies its business by offering hydroponic installations, training, cultivation consultation, and selling fresh fruit. This distinguishes the group from other farmer groups, classifying it as the Independent Agricultural and Rural Training Center (P4S). The monthly turnover is 10 million, with 50 percent of revenue derived from spinach harvest sales and 50 percent from installation and training services.

Partners are experiencing issues in production due to electricity costs. Waste of electrical energy and swelling of electricity costs cause farm income to decrease. The reliance on energy results in these farmer groups incurring the second-highest operational expense, following labor costs. Consequently, the NFT system exhibits a high recirculation frequency and less reliance on electrical energy than the DFT system (dos Santos et al., 2019). Farmers also face the challenge of reduced product quality due to their dependence on government-supplied electricity (Hariyanto et al., 2023). When power outages occur, plants begin to wilt, leading to a decline in quality, which may not meet the standards required by supermarkets as recipients of the supply. As stated by a previous study, plants grown using NFT systems are vulnerable to interruptions in water flow caused by power failures (Varmora et al., 2018), causing a rapid exhibit of wilting after water ceases to circulate inside the system (El-Kazzaz, 2017; Setiawati et al., 2023).

The intervention provided is the application of solar power as an alternative energy substitute for electricity use by the government. The solution offered is prioritized in the production sector, namely the use of solar panels in hydroponic systems. The use of this technology will change the costs observed through farmer group bookkeeping. The relevance of this training in agricultural enterprises lies in its potential to reduce dependency on conventional energy sources. This program begins with a vertical hydroponic installation that will increase spinach production. The hydroponic installation will be paired with solar panels as a source of electricity. Training on the installation and efficient use of solar panels in hydroponic systems can empower farmers to manage their energy needs sustainably, mitigate electricity-related expenses, and increase the profitability of their operation (Syahid et al., 2022). By utilizing solar panels as an alternative energy source, farmers can ensure a more stable and continuous energy supply for these critical systems, minimizing the likelihood of operational disruptions. This constant energy flow helps to maintain optimal growing conditions, preventing plant wilting and ensuring that crops meet the quality standards required by markets. Therefore, the use of solar energy not only reduces operational costs but also enhances the resilience of hydroponic systems, promoting better plant health and higher yields.

Hydroponic systems require significant electrical energy, primarily to operate water pumps and nutrient circulation (Budiyanto et al., 2021; Mai et al., 2023; Novaldo et al., 2022), with high electricity costs limiting widespread adoption (Soufi et al., 2023). As a tropical country, Indonesia has substantial solar energy potential, with average daily irradiation sufficient for solar energy use (Silalahi et al., 2021). The total global irradiance ranges from 2,111.9 to 2,427.5 W/m$^2$/year, with an average daily irradiation of around 5.86 kWh/m$^2$, deemed sufficient for solar energy utilization (Sigalingging & Honora, 2019). Integrating solar panels into hydroponic systems could reduce operational costs and support sustainable agricultural practices (Budiyanto et al., 2021; Syahid et al., 2022). Solar energy integration requires efficient management (Adiputra et al., 2024), particularly in optimizing water pump energy use for nutrient delivery (Khatri et al., 2024; Manurung et al., 2023; Sanubary et al., 2021). The utilization of electricity for water pump systems impacts operational costs; consequently, the efficient application of this energy may aid in increasing farmers' income (Raza et al., 2022). Research shows that solar-powered pumps achieve an efficiency of 31.19 percent and a positive net present value (Aziz et al., 2024). Alongside installation efforts, advancements in solar panel technology can be introduced to farmers through skills and knowledge enhancement programs.

This program aims to empower farmer groups through training in vertical hydroponic farming and the implementation of solar panels as a more efficient energy alternative. Farmer groups are expected to enhance existing resources to boost the productivity, cost-effectiveness, and sustainability of their enterprises. Farmer groups are assisted in enhancing the technical and managerial competencies necessary to address contemporary agricultural difficulties, diminish reliance on ecologically detrimental traditional energy sources, and enhance agricultural revenue.

## 2. METHODS

### Activity Design

Activities commenced with a preliminary survey from February to March 2024 and persisted from April to October 2024. The execution team is a combination of lecturers and students. The training participants are service partners affiliated with the Independent Agricultural and Rural Training Center (P4S) Hidroponik Generik (HG) as many as 11 members. The location is on Jln. Manunggal 2, RT 03/ RW 02, Petukangan Selatan Village, Pesanggrahan Subdistrict. The activities began with discussions and program design in collaboration with partners, focusing on identifying the type and objectives of hydroponic shelving. The Nutrient Film Technique (NFT) was established as the primary method, in which nutrient delivery is achieved through the circulation of water (Rumambi et al., 2023). The implementation of this program includes vertical hydroponic sysstems and solar panel systems. Vertical hydroponic components comprise a 2.5-foot PVC pipe, fiber roofing, net pot, half slab of Rockwool, half a meter of flannel, dip pump, 250 cc concentrate of AB Mix, spinach seeds, TDS meter, and a 50-litre nutrient reservoir. PVC material was selected due to its lightweight and robust properties, rendering it appropriate for supporting the load imposed on the hydroponic tower (Patel et al., 2024). The materials for the solar panel installation consist of four 200-watt monocrystalline solar panels from ST Solar, two 12V/100A batteries from VMP, a 60A solar charge controller from SAMOTO, and a 12V/1000W inverter from Solar Land PWM. The selection of monocrystalline solar panels was based on their superior efficiency of 8.14 percent, in contrast to the 7.57 percent efficiency of polycrystalline panels (Sigalingging & Honora, 2019; Songli et al., 2024).

### Implementation Methods

The methods implemented in this program encompass socialization, training, technological application, mentorship, evaluation, and sustainability. Production issues are the foremost priority that needs attention. The activities to be conducted encompass: (1) Socialisation: (a) Education on the advantages and installation of vertical hydroponics and the advantages and workings with solar panels; and (b) Education on bookkeeping and simple accounting training for farmers; (2) Technology implementation: (a) Provision of tools and materials; (b) Installation of vertical hydroponic installations; and (c) Solar panels for hydroponic water pumps; (3) Training and assistance support in nursery, growth, and maintenance of NFT hydroponics using solar panels for water pumps; and (4) Mentoring and evaluation: This community empowerment initiative employs three measures to assess the intervention's efficacy. The primary indicator is the partners' enhanced comprehension of vertical Hydroponics and solar panels. The second indicator is the enhancement of spinach production capacity. The third measure is the reduction in electricity expenses attributable to solar panels.

### Time and stages of program implementation

The activities began with discussions and program design in collaboration with partners, focusing on identifying the type and objectives of hydroponic shelving. The time and stages of program implementation are described in Table 1.

**Table 1.** Stages of activity implementation

| 1st Activity | Initial Survey | Time |
|---|---|---|
| Activities | - Discuss cultivation issues and potential solutions with partners | The second week of March 2024 |
| Goals | - Identifying partner challenges, precisely the electricity demand for hydroponic cultivation and the potential utilization of solar panels. | |
| **2nd Activity** | **Site Survey** | |
| Activities | - Discuss various alternatives with the team, partner, and practitioner in selecting the location of hydroponic installation and solar panel plant | The third week of July 2024 |
| Goals | - The determination of the location for the construction of hydroponics and solar panels. | |
| **2nd Activity** | **Installation and Construction of Vertical Hydroponics** | |
| Activities | - Assembling equipment and installing the vertical hydroponics, and project work supervision.<br>- Transferring seedlings to the vertical system, checking the water flow, and observing plants grow<br>- Cultivation assistance | The first to the third week of September 2024 |
| Goals | - The vertical hydroponic system has been erected and functions effectively, allowing partners to utilize it. | |
| **3rd Activity** | **Installation and Construction of Solar Panels** | |
| Activities | - Installing solar panels on the hydroponic water pump and project work supervision. | The second week of September 2024 |
| Goals | - Solar panels have been mounted on the hydroponic system within two 1000-hole planting racks and observed functioning effectively. | |
| **4th Activity** | **Monitoring the Working System of Solar Panels and Hydroponic** | |
| Activities | - Conducting or testing the water flow on hydroponics synchronized with solar energy and monitoring if there is a problem during the water flow.<br>- Summarize financial records to calculate costs and income | Last week of October 2024 |
| Goals | - The plants are observed healthy and farming data has been calculated | |

Three criteria are employed to evaluate the effectiveness of activities in executing this service program. The criterion for the effectiveness of program implementation is adherence to the scheduled activities and the predetermined number of sessions, necessitating effective collaboration between the team and participants. The team's success is assessed by their capacity to offer explanations and support to participants encountering challenges in practice. The assessment of the program's execution was conducted via partner satisfaction surveys.

The program's sustainability following the completion of the activities encompasses: (1) Establishing Hidroponik Generik as a partner of the university will enable the marketing of green spinach in the university's market; (2) Periodically selecting partners as the focal point for collaborative community service initiatives supported by internal funding from the university; and (3) Partner with the Agriculture Office to advance technology within farmer groups in the South Jakarta region.

## 3. RESULTS AND DISCUSSION

The results of activities that have been achieved include survey and observation activities, education of bookkeeping, installation of vertical hydroponics, and solar panels.

## Results

The results of activities that have been achieved include survey and observation activities, education of bookkeeping, installation of vertical hydroponics, and solar panels. The study of the problem revealed a significant electrical demand for the hydroponic system. The team offered solutions for installing solar panels on the constructed hydroponic system, including providing additional shelves and bookkeeping assistance.

### Survey and observation

P4S Hidroponik Generik manages a 200 $m^2$ area with a production capacity of 600 kg per month. The production facility consists of three Deep Flow Technique (DFT) beds, containing a total of 1,021 plant holes, and five Nutrient Film Technique (NFT) beds, with 6,000 plant holes. Some non-productive areas are used for storing unused items or are left vacant. These limited areas receive full sunlight exposure and are suitable for the installation of a hydroponic system with 54 plant holes. Additionally, there is an existing hydroponic installation with 54 plant holes that are currently not in use. This system will be reactivated for cultivation, contributing an additional 108 plant holes to the overall production capacity. The site receives adequate sunlight, particularly on the western side, where the storage area is located. The roof has been assessed and is suitable for the installation of four solar panels, with space beneath the roof for positioning the inverter, Solar Charge Controller (SCC), and batteries.

### Installation and construction of vertical tower hydroponics

The vertical tower hydroponics employs an NFT system with a thin stream of nutrients to moisten the rock wool and organize it in a vertical alignment. This vertical configuration maximizes space to enhance productivity, while the closed-loop system reduces resource consumption and waste (Khatri et al., 2024; Patel et al., 2024). This approach is optimal for industrial scale, offering maximized yields with comparatively minimum maintenance (dos Santos et al., 2019; Rumambi et al., 2023). Processes in hydroponic cultivation encompass seed sowing, transplanting seedlings into the hydroponic system, and harvesting.

The installation stages are as follows: (1) Structure Preparation. The galvalume frame is constructed under the hydroponic design and installed in a vertical and modular configuration; (2) PVC Pipe Installation. 2.5-inch PVC pipes were truncated to the requisite length for each tier. Utilizing a drill, the pipes were perforated around 15-20 cm apart for the net pot, ensuring the apertures were sufficiently enough for a 2 cm net pot; (3) Netpot Installation. The net pot is situated in the apertures bored in the pipe; (4) Preparing the Planting Media. Rockwool is hydrated and utilized for planting seeds. Upon sufficient maturity, the rock wool medium and seedlings are relocated to the net pot; (5) Flannelette Installation. The flannelette is affixed to the PVC pipe from the top to the bottom. The felt will absorb the nutritional solution and supply moisture to the plants; (6) Water Pump Installation. A water pump conveys nutritional solution via a hose connected to the PVC pipe; (7) Preparation of nutrient solution. Formulation of nutritional solution. The AB mix fertilizer solution is formulated and retained in the nutrient reservoir before application; and (8) Testing and Maintenance. The concentration of the nutrient solution is routinely assessed using a Total Dissolved Solids (TDS) meter.

### Cultivation assistance

The prepared seeds undergo a sowing process for 1-2 weeks before being directly placed into the hydroponic system. The seeding process involves several stages: preparing tools and materials (rockwool, seedling tray, nutrient solution, nutrient solution container, plant seeds), soaking rockwool in a nutrient solution with an Electrical Conductivity (EC) of 2.2, immersing seeds in rockwool to a depth of

1-2 mm, and placing the rockwool with seeds in seedling trays, which are kept indoors for 2-3 days until germination occurs.

Once the seeds have germinated, the seedling tray is positioned in a sunlit area. The base must be filled with nutritional solutions to prevent the rock wool from desiccating. In 1-2 weeks, the seedlings will develop two genuine leaves, signifying their readiness for transplantation into the hydroponic system. The nutrition solution is prepped before the seedling planting phase. During the growing phase of leafy vegetables, the nutrient solution maintains an electrical conductivity of 3.0-3.5. The formulated fertilizer solution is introduced into the hydroponic system's water reservoir. Seedlings from the tray, embedded in rock wool, are positioned into the net pot within the hydroponic pipe.

The harvesting of spinach depends on the variety. Green spinach requires 11 days for sowing and 14 days for planting, while red spinach necessitates 14 days for seeding and is suitable for harvest 17 days post-planting. The sanitized hydroponic system and net pot are suitable for replanting. The NFT hydroponic system operates vertically, conserving acreage relative to horizontal systems (Patel et al., 2024; Rumambi et al., 2023). In this program, the team and partners installed the equipment and conducted tests on the vertical tower model. In the prior state, the partners utilized the bed type (without leveling) and later the partners learned to cultivate plants in vertical type. Figure 1, 2, and 3 illustrates the situations before and after.



**Figure 1.** Existing condition of non-tier hydroponic bed (before)
**Figure 2.** Installation process
**Figure 3.** Addition of NFT vertical tower hydroponic (after)

### Installation and construction of solar panels

The outcome of the implemented technique is installing solar panels on hydroponic systems. Among the DFT and NFT systems utilized by the partners, the NFT system has been chosen to be integrated with solar panels for its superior potential to enhance energy efficiency (Gillani et al., 2022). Solar energy is stated to produce energy under many climatic situations (Pachaivannan et al., 2024). The DC water pump system operates effectively between 11:00 and 15:00 (Sigalingging & Honora, 2019). During inclement weather in the rainy season, the energy produced by the 20 W solar panel enables the device to operate at night for about two hours without dependence on local electricity (Alam et al., 2022). A separate study indicates that solar panels with a capacity of 10 watts peak can charge the battery to 80 percent for Hydroponics (Rochman & Krama, 2023).

The product requirements outlined in this program comprise four 200-watt monocrystalline solar panels from the ST Solar brand, two 12V/100Ah batteries from the VMP brand, a 60A solar charge controller from the SAMOTO brand, and a 12V/1000W inverter from the Solar Land PWM brand. The stiff PVC material possesses intrinsic lightness and durability qualities, rendering it ideal for enduring the strain imposed on the hydroponic tower (Patel et al., 2024). The selection of monocrystalline solar panels was based on their efficiency rate of 8.14 percent, which surpasses that of polycrystalline panels at 7.57 percent (Sigalingging & Honora, 2019; Songli et al., 2024). Figure 4 illustrates the tools and materials supplied to the partners.


**Figure 4.** Tools on solar panel installation for water pumping machine: Solar Charge Controller (SCC) 60A, inverter 1000W, monocrystalline solar panel, panel box, accu 12V/100 A, and water pump

Four monocrystalline solar panels, each with a capacity of 200 Wp, generate electrical energy from sunshine. The cumulative output of all the panels is 800Wp. These panels transform solar energy into direct current electricity to charge the battery and power the device. Electrical energy generated by solar panels is stored in a 12V/100Ah battery. Two batteries are configured in tandem to enhance storage capacity, guaranteeing the energy supply for the water pump in the absence of sunlight (Songli et al., 2024). The 60A SCC manages battery charging from the solar panel, inhibiting overcharging or excessive discharge. The SCC regulates the current and voltage entering and exiting the battery, maintaining its ideal condition and prolonging its lifespan. When the solar panel is not illuminated or produces less than 10.7 Volts, the SCC disconnects the voltage current from both the solar panel and the battery, immediately switching to the source power provided by the State Electricity Company (PLN) (Rumambi et al., 2023). The 12V/1000W inverter transforms the DC electrical energy stored in the battery into AC electrical energy. The inverter is crucial if the water pump or other gadgets utilized in the hydroponic system necessitate AC electricity. A 1000W inverter permits the operation of electrical equipment, totaling a maximum power of 1000W. The electricity will be sent to the water pump that supplies water to two hydroponic racks, each with a capacity of 1,000 planting holes, thereby ensuring that the plants receive the necessary water and nutrients.

Installation steps are mentioned as follows: (1) Solar panel installation. The solar panel frame or stand is positioned at the chosen site with a 30-45-degree incline. Four solar panels are affixed to the roof with brackets; (2) Solar panel connection. The solar panels are interconnected with MC4 cables and arranged in series and parallel configurations to elevate the voltage; (3) Installation of Solar Charge Controller (SCC). The cable from the solar panel is linked to the input terminal of the SCC; (4) Battery connection. The two 12V/100 Ah batteries are connected parallel to enhance capacity while maintaining polarity; (5) Inverter Installation. The inverter is attached to the batteries, and its AC output is to be linked to the designated equipment; (6) Fuse and circuit breaker installation. To provide system protection, fuses, and circuit breakers are installed on the connections between the solar panels and the Solar Charge Controller (SCC) and between the battery and the inverter; and (7) System testing. Testing is conducted utilizing voltage and amperage meters to assess energy flow. Monitoring is essential to assess the battery charge level and to remove dust or dirt from the solar panels.

The solar panel installation occurred on the roof of the Pesanggrahan hydroponic garden warehouse. The placement employed an open warehouse filled with surplus items. Figure 3 illustrates the state before and after the installation.

**Figure 5.** Solar panel installation program, existing condition of the roof of the partner warehouse (before), team and partner's, and 800wp solar panel installed on the roof (after)

## Discussion

### Application of technology and innovation to the community

The program facilitates the integration of vertical hydroponic and solar panels for water pumping systems, thereby improving agricultural productivity and increasing revenue. The active engagement of the community is vital for the successful execution of this program. This document elucidates the significance of community engagement in this program.

### The relevance of providing support for vertical hydroponic and solar panel

Hydroponics and solar energy contribute to a more sustainable agricultural system by minimizing the use of water, land, and fossil fuels, while also safeguarding the environment through the reduction of toxic pesticides and fertilizers. Below is how this program contributes to agriculture sustainability.

### Innovation in agricultural technology

Vertical hydroponics enable farmers to cultivate vegetables and other crops more effectively on constrained land while minimizing water and pesticide usage. Before the initiative, the land area required optimal utilization. The vacant property was utilized for the storage of unused pots and nonproductive ornamental potted plants. Incorporating vertical hydroponic and utilizing vacant racks led to a productivity boost of up to 4 kg per planting cycle (2 weeks). A study indicates that the vertical farming system yields plant heights equivalent to those of the horizontal farming system, measuring 35 cm, with a leaf count of 14 strands, according to commercial norms for spinach plants (Putri et al., 2022).

### Energy conservation with solar panels

Solar panels for water pumping systems harness solar energy for irrigation, decreasing operational expenses associated with traditional electricity or fossil fuels (Sarathkumar, 2019). The outcomes of the program execution are measurable. Mathematically, the power generated and the duration of use for the water pump are shown in Table 2.

**Table 2.** Power Calculation and Usage Time

| Description | Calculation |
|---|---|
| Installed capacity of solar panel | 800 Wp |
| Estimated daily effective sunlight hours | 4 hours |
| Total daily power | 3200 Wh |
| Total battery capacity 200 Ah (2 x 100 Ah) 12 V | 2400 Wh |
| Maximum output | 70 percent |
| Usable capacity | 1600 Wh |
| Power consumption of the pump | 120 w |
| Usage time | 13 hours |

The solar panel has an installed capacity of 800 watts peak. This solar panel generates 3200 watts of electricity daily. The capacity of one battery is 100 Ah at 12 Volts. Hence, the capacity of the installed battery is 200 Ah at 12 Volts. The ideal power output is 70 percent, with a consumption threshold of 1600 Wh, sufficient to operate two water pumps for 12 to 13 hours of uninterrupted operation. The solar panel operated effectively throughout nighttime and inclement weather for nearly a month of observation. This aligns with Sanubary et al., (2021), who asserted that solar panels on water pumping systems can provide over 0.48 kWh of electricity daily, alleviating concerns over weather fluctuations. According to other researchers, the energy generated by two 100 WP Monocrystalline Solar Panels lighted the agricultural region for 12 hours (Setiyono et al., 2024), and three solar panels may power water pumping devices for up to 24 hours (Novaldo et al., 2022). Implementing solar panels decreases reliance on energy, resulting in a monthly reduction of IDR 356,000 in electricity expenses in HG, constituting a 10 percent decrease in overall farming expenditures.

### Reduction of defective products

Defective products are typically converted into juice and marketed to the local population. The damage arises from an irregular flow of nutrients (El-Kazzaz, 2017; Setiawati et al., 2023). Plants deficient in nutritional water exhibit wilted stems and fallen leaves (Baiyin et al., 2021). Another indication is that the coloration of the plant leaves also becomes brown (Setiawati et al., 2023). Solar panels facilitate the uninterrupted operation of water pumps, supplying plants with essential water and nutrients (Manalu et al., 2023; Novaldo et al., 2022). The implementation of solar panels aids in regulating water flow, hence minimizing product damage to 16.8 kg per month, approximately 7 percent of production at HG farms.

### The impact (usefulness and productivity)

The potential utility of solar panels for water pumping systems is considerable. The installed capacity of 800 wp solar panels produces 1600 Wh of electricity daily, sufficient to continuously operate the pump on two hydroponic racks for 12 to 13 hours. This program is beneficial in 2 ways, namely the direct benefits through saving electricity by 10 percent of the total cost due to solar panels, a program to add vertical hydroponic production racks linked to solar panels, as well as reducing damaged products due to a stable flow of nutrients after solar energy, and the indirect benefits through training services to other farmers. The cost decrease is -IDR356,000, affecting 10 percent reduction of the total monthly expenditure. A solar panel system regulates water flow to reduce the risk of product damage to 7 percent. The NFT system featuring 108 planting holes contributed to a 3 percent increase in yield, up from 240 kg at the HG farm. Business diversification is augmented by vertical hydroponics training, with a potential revenue of 2 million per month. The program projected a potential monthly increase in farm income of 15 percent.

**Table 3.** Change in production and income

| Monthly Component | Before | After | Change | |
|---|---|---|---|---|
| | | | Unit | % |
| Product sell | Rp 14.880.000 | Rp 15.004.000 | Rp 124.000 | 0,8 |
| Training | Rp 900.000,00 | Rp 2.279.000 | Rp 1.379.000 | 153,2 |
| **Total Revenue** | Rp 15.780.000 | Rp 17.283.000 | Rp 1.503.000 | 9,5 |
| Cost of energy | Rp 540.000 | Rp 184.000 | -Rp 356.000 | -66 |
| Total production cost | Rp 3.561.333 | Rp 3.217.333 | -Rp 344.000 | -10 |
| Product defect | 30 kg | 27,9 kg | -2,10 kg | -7 |
| Production (vertical hydroponic) | 240 | 248 | 8 | 3 |
| **Total Income** | Rp 12.218.667 | Rp 14.065.667 | Rp 1.847.000 | 15 |

## Programme evaluation

The implementation team assisted the partners in ensuring that the vertical hydroponic and solar panel programs were congruent with their objectives. The program evaluation was performed utilizing the indicators presented in Table 4.

**Table 4.** Activity evaluation

| Indicator | Condition Before | Condition After |
|---|---|---|
| Enhanced comprehension of vertical hydroponics among partners | Partners possess knowledge regarding vertical hydroponics but have not consistently implemented it. | Partners possess expertise in vertical hydroponics, implement it, and produce an additional 2kg of spinach per production cycle. |
| Enhanced comprehension of solar panels among partners | Partners have yet to comprehend the application of solar panels as renewable energy in hydroponics. | Partners comprehend the application, utilization, and maintenance of solar panel installation. Partners gain from the reliability of the panels' energy in the hydroponic system during power interruptions. |
| Enhanced spinach production capacity | The average spinach yield at HG's farm is 240 kg monthly. | The average monthly spinach production at HG farm is 248 kg, with product defect reduced by 7 percent |
| Reduced electricity expenses resulting from the installation of solar panels | The monthly cost of electricity is IDR540,000 | Electricity expenses decreased to an average of IDR184,000 monthly |

## Supporting and Inhibiting Factors

The program is supported by various aspects, such as professional provided, farmer's experience in hydroponic systems, financial aid for materials, and support from local government. The program is assisted by trainers skilled in renewable energy and hydroponic systems. Their knowledge ensured proper installation, operation, and maintenance of the solar panels and water pumps. The trainers were informative to the farmers and how they could employ hydroponic farming together with incorporating solar technology. This program is financially supported by the Indonesian Directorate of Research, Technology, and Community Service. This aid helps in promoting sustainable agriculture and renewable energy projects for farmers. The local government assistance included improvements in local infrastructure, facilitating easier access to the necessary resources and enabling smoother implementation of solar and hydroponic systems. The local government played a role in monitoring the program's outcomes, ensuring that it met its objectives and providing valuable data for future improvements.

Besides supporting factors, there are several inhibiting aspects to the program's sustainability including high reinvestment costs, the need for additional solar panel capacity, and a long learning curve associated with solar technology. The upfront costs for purchasing and installing solar panels and hydroponic systems can be substantial (Durga et al., 2024). The energy needs of water pumps and other equipment can fluctuate, and the current solar panel capacity may not always be sufficient to meet these needs. Farmers might have to purchase more panels, which will raise expenses and add complexity to their planning (Prabowo et al., 2020). Ongoing costs for the system's maintenance, repair, and potential upgrades will also put farmers under considerable financial pressure (Rahman et al., 2023). They may be unwilling to recontribute if the program does not bring immediate returns. The funds for solar and hydroponic investments could go to more important agricultural needs, causing reluctance to adopt them.

A "long learning curve" refers to the extended period and effort required for individuals or groups to acquire the necessary skills and knowledge to effectively use or master a new technology or system. In the context of new technologies like solar panels, it implies that farmers may face significant challenges and require extensive training before they operate it confidently (Orosz et al., 2024). If farmers still rely on old methods, they might be reluctant to change and it will take them a lot of time to learn how to operate it (Mardiansyah et al., 2023). In other words, levels of investment could have a positive or negative impact on the equipment's utilization rate. These inhibitory factors pose considerable obstacles to the program, potentially hampering implementation and effectiveness. In future programs, addressing these issues through targeted support, education, and financial assistance will be critical in future similar programs to overcome barriers and improve program performance.

## The change in partner's knowledge

The success of this program was assessed using pre-test and post-test results. Data analysis was conducted using SPSS version 26 for Windows, employing a paired sample t-test to evaluate whether there is a change between before and after programs.

Compared to the participants' baseline knowledge, the test scores showed a significant improvement after the program was implemented. According to the t-test results, the mean pre-test score was 56.36, while the mean post-test score was 81.82. The change in scores was reflected in the mean pairwise difference of -25.455 or 45 percent change. The Paired Samples Test showed that this difference was statistically significant (Sig. 2-tailed = 0.000 < 0.05). Therefore, it can be concluded that there is a significant difference in participants' understanding of solar panel applications before and after the program. This indicates that the program is effective in improving participants' knowledge.

**Table 5.** Data analysis

**Paired Samples Statistics**

| | | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Pair 1 | PreTest | 56.36 | 11 | 15.015 | 4.527 |
| | PostTest | 81.82 | 11 | 14.013 | 4.225 |

**Paired Samples Test**

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95 percent Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | PreTest - PostTest | -25.455 | 15.725 | 4.741 | -36.019 | -14.890 | -5.369 | 10 | .000 |

## 4. CONCLUSION AND RECOMMENDATIONS

This community service initiative seeks to equip economically productive community groups with new skills and knowledge through training. The results of this activity are relevant to the goal of creating energy independence and income for farmer groups through the implementation of solar panels on hydroponic water pump machines. Partners benefit from reduced electricity expenses via solar water pumps, the potential for enhanced income through energy savings for water pumping, and the development of environmentally sustainable. Installing solar panels diminishes electricity expenses and mitigates product damage, enhancing partner revenue. The potential utility of solar panels for water pumping systems is considerable. The installed capacity of 800 wp solar panels produces 1600 Wh of electricity daily, sufficient to continuously operate the pump on two hydroponic racks for 12 to 13 hours. This invention could reduce 66 percent electricity power usage which is 10 percent lower than the total monthly expenditure. Together with the production of vertical hydroponic training, this program is worth increasing farm income by 15 percent. Program evaluation brings satisfaction to the partner. The significant difference in participants' understanding of solar panel applications before and after the program was as much as 45 percent. In conclusion, this activity enables the community to harness renewable energy and enhance their financial independence through agricultural endeavors.

Follow-up and supplementary solar panels are necessary to attain optimal energy utilization. Three recommendations have been proposed to ensure the sustainable implementation of the program. First, collaboration with external partners must be enhanced to ensure broader engagement and responsiveness to the ongoing program. Second, the program's impact is still under evaluation since solar panels represent a long-term investment. Continuous support from academic institutions is essential to monitor and assess progress. Third, research on farming after a long period (like a quarter or semester) of the program's implementation is recommended to identify significant changes and their effects on farmers' households. Collaboration among the government, educational institutions, and business partners is crucial to ensuring the program's sustainability.

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