

Utilization of Solar Panel Energy Technology for Energy Independence in Household-Scale Agricultural Plants

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Abstract

The need for electrical energy in the household-scale agricultural sector is increasing, especially to support irrigation systems and simple agricultural technologies. This research and community service activity aims to implement and evaluate the use of solar panel technology as an independent energy source for small farmers. The system designed uses 100 WP monocrystalline solar panels, a 12V 3.5 Ah dry battery, and a 12V DC water pump as the main components. The results of implementation show that the solar panel system is able to provide stable energy for operating a water pump with a power of 22 watts and a flow capacity of 800 L/hour. Monitoring indicates that the charging voltage remains within a safe range (12.9V) and can optimally support the growth of hydroponic plants such as pakchoi. Although there are several technical challenges such as the potential for short circuits and the lack of protective systems, these issues can be addressed through safe installation design and technical education for users. In conclusion, solar panels have great potential to realize energy independence in household-scale agriculture, especially in rural areas, if supported with appropriate financing schemes and training.

Keywords: Solar Panels, Renewable Energy, Household Agriculture, Energy Independence, Hydroponics.

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Introduction

Energy is one of the crucial factors in supporting agricultural activities, including those at the household scale. Energy needs in the agricultural sector cover various aspects such as irrigation, lighting, and processing of agricultural products. However, in many remote and rural areas in Indonesia, access to electrical energy remains limited. This is caused by unequal electricity infrastructure and a high dependence on fossil fuels, which are not only expensive but also environmentally unfriendly. These limitations can hinder agricultural productivity and efficiency, and reduce the quality of life of local communities.

As a solution to this problem, the use of renewable energy, such as solar energy, becomes highly relevant. Indonesia, with its geographic location in the tropical region, has great potential for developing solar energy. This potential can be seen from the high daily solar insolation rate, which ranges from 4.5 to 4.8 kWh/m²/day (Ari Rahayuningtyas, 2014).

Solar panel technology, or photovoltaic (PV), can convert sunlight into electrical energy that can be used for various agricultural purposes, such as irrigation pumps, plant lighting systems, and other agricultural tools. The utilization of solar panel technology at the household scale for agriculture not only helps provide environmentally friendly energy but also enhances energy independence for farmers. By using a renewable energy source, farmers can reduce their dependence on unstable and often expensive external energy supplies. In addition, the use of solar panels can also reduce greenhouse gas emissions, in line with global efforts to address climate change.

However, the application of solar panel technology in household-scale agriculture still faces several challenges, such as high initial costs, limited technical knowledge among farmers, and the need for regular maintenance. Therefore, this research aims to explore the potential and challenges in using solar panel technology to support energy independence in household-scale agriculture. It is hoped that effective and sustainable solutions can be identified to improve agricultural productivity and the welfare of rural communities in Indonesia.

The utilization of solar panel technology in household-scale agriculture also has the potential to provide significant economic impacts. By shifting to more economical and sustainable renewable energy sources, farmers can reduce operational costs associated with fossil fuels or conventional electricity. This is especially important for small-scale farmers who often face financial constraints in accessing stable and affordable energy sources. Moreover, the use of solar energy can open opportunities for farmers to develop more innovative agricultural practices, such as automated irrigation systems or artificial lighting to increase crop production.

In the global context, the use of solar energy in agriculture also contributes to climate change mitigation efforts. By reducing dependence on fossil fuels, greenhouse gas emissions can be significantly lowered, supporting emission reduction targets agreed upon in international treaties.

In Indonesia, the development of renewable energy, including solar energy, is part of the government's commitment to achieving a cleaner and more sustainable energy mix. Therefore, the application of solar panel technology in the agricultural sector not only supports environmental sustainability but also aligns with national policies promoting energy transition.

However, achieving energy independence through solar panel utilization in household-scale agriculture requires a comprehensive approach. This includes technical, economic, and social aspects. From the technical side, efficient technology that suits specific agricultural needs is required. From the economic side, affordable financing models and incentives from the government or financial institutions are needed to encourage adoption. Socially, education and training for farmers are crucial to ensure they understand the proper use and maintenance of solar energy systems.

Thus, this research will explore these various aspects with the main objective of formulating effective strategies for implementing solar panel technology in household-scale agriculture. The results are expected to contribute significantly to improving energy independence, agricultural productivity, and farmer welfare in Indonesia, as well as supporting global efforts to address climate change challenges.

Based on the above background, the author is interested in conducting this final project research entitled "Utilization of Solar Panel Energy Technology for Energy Independence in Household-Scale Agricultural Plants."

1.2 Research Objectives

The objectives of this research are as follows:

1. What is the potential and effectiveness of utilizing solar panel technology in supporting energy independence in household-scale agriculture in Indonesia?
2. What are the technical challenges faced in implementing solar panel technology for household-scale agriculture, and how can they be overcome?
3. What financing schemes are most effective to support the adoption of solar panel technology in the household-scale agricultural sector?

Literature Review

1. Automatic Parking System

An automatic parking system is a modern solution to improve efficiency and safety in managing vehicle access in parking areas. This system usually combines sensor technology, microcontrollers, and mechanical devices such as servo or DC motors to operate the gate barrier automatically. According to Wahyuni et al. (2019), automatic parking systems can reduce vehicle queues and minimize human errors in parking management, making the system more reliable and efficient.

2. Microcontroller

A microcontroller is the main component in automation systems, functioning to control device operations based on input from sensors. One of the most commonly used microcontrollers for prototype development is the Arduino Uno, as it is open-source, easy to program, and supported by a large user community (Putra & Suryadi, 2020). The microcontroller controls data flow and activates actuators (motors) according to the predefined program logic.

3. Vehicle Sensor

In an automatic parking system, vehicle detection is crucial for controlling the gate barrier's opening and closing automatically. Commonly used sensors include ultrasonic sensors, infrared (IR) sensors, and magnetic sensors. Ultrasonic sensors work by emitting high-frequency sound waves and measuring the reflection time to detect object distance. According to Rahman & Nurhadi (2022), ultrasonic sensors are highly effective at short distances because they provide accurate, real-time detection.

4. Motor Drive

Electric motors are used as actuators in parking systems to move the gate barrier. Servo motors are among the most commonly used types because they offer high precision in position control and fast response times. Research by Siregar & Ahmad (2021) shows that servo motors provide stable motion according to control signals sent by the microcontroller.

5. DC Motor

A DC (direct current) motor is one of the most widely used types of electric motors in industrial and automation applications. This motor works by converting electrical energy into mechanical energy, which is then used to drive various devices such as parking gates, fans, or compressors. A DC motor consists of two main components: the stator (stationary part) and the rotor/armature (rotating part). According to Nurmasyithah (2022), electric motors account for about 70% of industrial power consumption. The working principle of a DC motor depends on the change in voltage direction through the commutator, which allows the rotor to continuously rotate within a magnetic field (Rahim Siregar, 2022).

6. Parking Management System Integration

To ensure that the parking gate control system operates optimally, it must be integrated with a parking management system. This system can record data on vehicles entering and exiting, monitor parking capacity in real time, and generate parking space usage reports. According to Susanti & Ramadhan (2020), such integration makes the system smarter, more adaptive, and more efficient in responding to real-world conditions.

Research Method

Flowchart Description

1. Start: The initial point of the process of utilizing solar panels in household-scale agricultural systems.
2. Analysis of Agricultural Energy Needs: Identifying electrical requirements for household farming activities such as water pumps, moisture sensors, and irrigation systems.
3. Planning and Designing the Solar Panel System: Determining the number of panels, inverter capacity, storage systems (batteries), and electrical network configuration.
4. Solar Panel Installation: Physical installation of panels at the home or farm location that receives optimal sunlight exposure.
5. Conversion of Solar Energy into Electricity: Solar panels capture sunlight and convert it into electrical energy through photovoltaic cells.
6. Distribution of Energy to Agricultural Devices: The generated electricity is used to operate water pumps, drip irrigation systems, soil moisture monitoring devices, and other farming equipment.
7. System Monitoring and Maintenance: Monitoring panel efficiency, battery condition, and conducting periodic maintenance to ensure the system operates optimally and sustainably.
8. Energy Independence Achieved: Farmers can carry out agricultural activities independently without relying on external energy sources (such as grid electricity or fuel).
9. End: The system continues to operate sustainably with independent management.

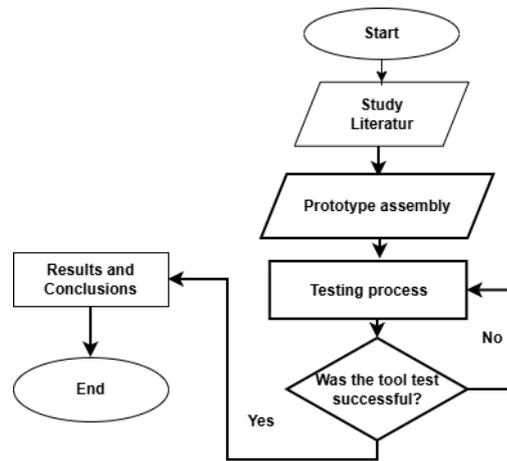


Figure 1. flowchart

Results

1. Solar Panel Circuit Installation

The solar panel system used in this activity is designed to meet the electrical energy needs of household-scale agriculture independently. Solar energy is captured by the solar panel and converted into direct current (DC), then delivered to the solar charge controller (SCC), which regulates the flow of electricity before it is stored in a dry battery. This battery stores energy that will later be used to operate agricultural equipment such as water pumps, irrigation systems, or moisture sensors. The main components of the system consist of a 100 WP monocrystalline solar panel, a 10A solar charge controller (12V/24V) with intelligent PWM charging mode, a dry battery, and an inverter (optional) if the devices require alternating current (AC). The panel is installed in a location that receives at least 5–6 hours of sunlight per day. The connections between components use appropriate DC cables to ensure safe and efficient operation. All electronic equipment is stored inside an enclosed box to protect it from weather conditions. This system is simple but effective in supporting energy independence for small-scale farmers.

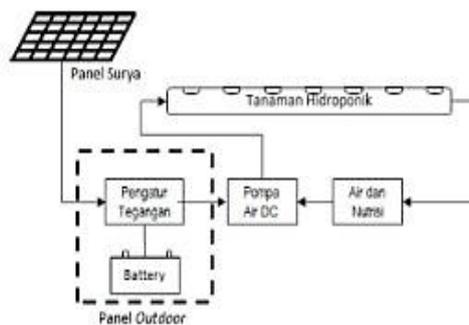


Figure 2. Solar Panel Wiring Diagram



Figure 3. Electrical System with Solar Panel

Technical Calculations with Input Formulas

1. Calculation of Pump Power and Current

To determine the current required by the pump, the basic formula that relates power, voltage, and current is used:

$$I = \frac{P}{V}$$

By inserting the values of power ($P = 22 \text{ W}$) and voltage ($V = 12 \text{ V}$), the current obtained is:

$$I = \frac{22}{12} = 1.83 \text{ A}$$

This means the pump requires approximately 1.83 amperes during operation. The DC water pump used in the system has a power rating of 22 watts and operates at 12 volts. Using the formula $I = P/V$, the calculated current shows that the pump requires 1.83 A to function properly.

2. Calculation of Daily Energy Consumption of the Pump

The energy requirement of the pump is determined based on its daily operating duration. The operating time supported by the battery is calculated using the formula:

$$t = \frac{Wh}{P}$$

By inserting the safe usable battery energy of 33.6 Wh and the pump power of 22 W, the operating time is:

$$t = \frac{33.6}{22} = 1.52 \text{ hours}$$

Electrical energy consumption is also calculated using the formula $E = P \times t$, where P is pump power and t is the operating duration. If the pump operates for 1 hour per day, the required energy is $E = 22 \times 1 = 22 \text{ Wh/day}$. If the pump runs for 2 hours, the energy consumption becomes $E = 22 \times 2 = 44 \text{ Wh/day}$. These calculations facilitate the determination of daily energy needs according to operational requirements.

3. Battery Capacity Calculation

The battery used in the system has a specification of 12 volts with a capacity of 3.5 Ah. The maximum energy that can be stored by the battery is calculated using the formula $Wh = V \times Ah$. By inserting the battery data into the formula, the energy storage capacity obtained is $Wh = 12 \times 3.5 = 42 \text{ Wh}$. However, a battery should not be discharged to 100% because it may accelerate battery degradation. Therefore, only about 80% of the total capacity is considered safe to use. The safe usable energy is calculated using the formula $Wh_{\text{safe}} = Wh \times 0.8$,

resulting in $Wh_{safe} = 42 \times 0.8 = 33.6$ Wh. This value becomes the basis for determining how long the battery can supply energy to the pump.

4. Evaluation of Pump Operating Time from the Battery

To determine how long the pump can operate using the energy stored in the battery, the formula $t = Wh/P$ is used. With safe battery energy of 33.6 Wh and pump power of 22 watts, the operating duration of the pump becomes $t = 33.6/22 = 1.52$ hours. This indicates that with a fully charged battery, the pump can run for approximately 1.5 hours before the battery needs to be recharged.

5. Calculation of Energy Generated by the Solar Panel

A 100 WP solar panel generates energy based on the duration of effective sunlight each day. The energy produced by the solar panel is calculated using the formula $E_{panel} = P_{panel} \times \text{sun hours}$. With an average sunlight exposure of 4.7 hours per day, the panel produces $E_{panel} = 100 \times 4.7 = 470$ Wh/day. In real-world conditions, there are system losses such as panel inefficiency, cable losses, and controller losses, which reduce usable energy to approximately 70%. The net usable energy is calculated using $E_{net} = E_{panel} \times \eta$, resulting in $E_{net} = 470 \times 0.7 = 329$ Wh/day. This shows that the solar panel generates far more energy than required to operate the pump and charge the battery.

6. Monitoring the Growth of Hydroponic Plants

To ensure sustainability of the solar-powered hydroponic system, it is important to conduct regular monitoring of both the solar panel system and plant development. Key components such as the solar charge controller (SCC), battery, and water pump must be in optimal condition to ensure a stable power supply. During the monitoring process, the SCC display showed a charging voltage of 12.9 volts, indicating that the solar panel system was actively charging the battery. Direct measurement of the dry battery showed a voltage of 12.7 volts, which is within the safe range and adequate for operating the 22-watt DC water pump. Under these conditions, nutrient water supply to the plants can run smoothly.

In a hydroponic system, the availability of water and nutrients is a crucial factor affecting plant growth. Hydroponic plants such as pak choi contain about 80–90% water, so a consistent and sufficient flow of nutrient solution is essential. Therefore, nutrient monitoring is carried out periodically, especially regarding nutrient concentration (PPM) and water acidity level (pH). In this study, pak choi plants were used as the hydroponic crop with a harvest period of approximately 35–40 days. Nutrients were supplied using AB-Mix solution, with a maximum PPM level of 1150, and water pH maintained between 6 and 7. Monitoring was conducted from seedling stage until harvest, with nutrient levels adjusted according to plant age in Days After Planting (DAP).

Discussion

1. Potential and Effectiveness of Solar Panel Technology in Supporting Energy Independence for Household-Scale Agriculture in Indonesia

Indonesia has immense solar energy potential due to its location along the equator, with average sunlight intensity of 4–5 kWh/m² per day throughout the year. This makes solar panel technology highly feasible for development in household-scale agriculture, particularly in rural areas with limited access to electricity or frequent power outages. Based on field implementation results, the solar panel system is capable of independently supplying electrical energy to operate water pumps, irrigation systems, and plant monitoring devices. The

effectiveness of solar panels is also evident from the stable energy supply, which ensures agricultural equipment continues to function even at night through stored battery energy. With proper system configuration, small-scale farmers can carry out their agricultural activities without reliance on conventional electricity networks.

2. Technical Challenges in Implementing Solar Panel Technology for Household-Scale Agriculture and Solutions

Several technical challenges encountered in implementing solar panels in household farming include:

- a. Installation and component quality: Improper installation or use of unsuitable cables and connectors may cause short circuits or equipment damage.
- b. Lack of system protection: Many simple systems lack safety components such as fuses or reverse current protection, increasing the risk of panel or battery damage.
- c. Limited maintenance and monitoring: Farmers' limited knowledge of how to maintain panels, batteries, or other system components can lead to premature system failure.

To overcome these challenges, the following solutions are necessary:

- a. Providing basic technical training to users so they understand installation, maintenance, and troubleshooting.
- b. Designing a simple yet safe system, such as adding fuses, MCBs (Mini Circuit Breakers), and grounding systems.
- c. Supplying clear operational guidelines and encouraging routine monitoring of battery voltage, panel performance, and pump condition.

3. Effective Financing Schemes to Support Solar Panel Adoption in Household Agriculture

One of the main barriers to adopting solar panel technology is the relatively high initial installation cost, especially for small farmers. Therefore, an inclusive and sustainable financing scheme is necessary. Several effective financing models include:

- a) Government subsidies or village assistance programs for initial procurement of solar panel systems.
- b) Soft loans or installment schemes through farmer cooperatives or village-owned enterprises (BUMDes), allowing farmers to repay using agricultural income.
- c) Pay-As-You-Go (PAYG) models, commonly used in developing countries, where users pay based on actual electricity usage through prepaid systems.
- d) Partnerships with the private sector or corporate social responsibility (CSR) programs, enabling subsidized technology distribution for community empowerment.

With the right combination of technical support and financing schemes, the adoption of solar panel technology in household-scale agriculture has strong potential to grow rapidly, contributing to national energy independence based on rural development.

Conclusion

The utilization of solar panel technology in household-scale agriculture in Indonesia shows great potential in supporting energy independence, especially in rural areas that are not fully connected to the electrical grid. This system has been proven capable of providing a stable

electricity supply to operate agricultural equipment such as water pumps and irrigation systems, as well as supporting the sustainability of independent farming.

Although there are technical challenges such as limited user knowledge, risks of damage due to short circuits, and insufficient protection systems, these issues can be addressed through training, safe system design, and regular monitoring. Financial support is also a crucial factor in increasing the adoption of this technology. Schemes such as government subsidies, soft loans, or partnerships with the private sector can offer solutions to overcome the high initial installation costs. With the right approach, solar panel technology can become a practical solution for achieving independent, efficient, and environmentally friendly household-scale agriculture in Indonesia.

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