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Economical sustainability of integrated photo voltaic and hydroponic systems for rural areas

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Abstract

Hydroponic plantations are an effort of future agricultural technology, and this is due to population growth and increasingly saving agricultural land. Besides that, hydroponics can trigger rural economic development by opening employment opportunities for rural areas. The realization of hydroponics in rural areas that are not connected to the grid can use solar energy to circulate water continuously. The components of photo voltaic systems have been designed to the needs of the hydroponic system. Photo voltaic technology has been used for a long time for lighting in remote areas. Integrating the photo voltaic system with hydroponics is a synergistic effort to use energy productively. The case the demand for vegetables in rural areas is minimal, with limited land and the level of land productivity that depends on the availability of fertilizers. The economical method for analyzing the integrating system of photovoltaic and hydroponic systems is based on PBP, CCP, and ROROI. The results obtained for kale based on the PV-hydroponic integration system have a return on investment (PBP) of 13.5 months, cumulative cash posit (CCP) of 1.84, and Rate of Return on Investment (ROROI) of 8.01%. Adding the second and third hydroponic plant modules can reduce PBP to 6.2 months and 5.2 months, respectively. Likewise, CPP increased from 1.84 to 3.68 and 5.21, respectively. Meanwhile, ROROI rose from 8.01% to 11.43% and 13.34%, respectively.

Keywords: *Hydroponic system; PhotoVoltaic system; Kale; PBP; ROROI*

1. Introduction

Vegetable fields in rural areas are generally empowered to supply vegetables for urban areas. Remote areas depend on the supply of vegetables from other regions. Hydroponic plants to meet the needs of vegetables with relatively low consumption of fertilizers is a solution to supply the needs of vegetables at low prices. In addition, remote areas do not yet have access to electricity for productive purposes.

The photo voltaic system integration technology with the hydroponic system has been applied in Cihanjuang village. Cihanjuang Village is one of the villages in the Parongpong District, located between the foot of Mount Tangkuban Perahu and Burangrang, with the border area between Bandung Regency and Cimahi City. In the early 1980s, Cihanjuang Village was known as a center for producing gardens and agriculture, which could supply not only the Bandung area but also Jakarta and the border areas of Central Java. The agricultural products are secondary crops, vegetables, rice, and fruits, in addition to cattle and goat farms. However, population growth and the development of residential areas, which provide beautiful panoramic views of the surrounding nature, attract entrepreneurs to build villas, residential areas, and recreational objects, causing the area of agricultural land and plantations to shrink.

Cihanjuang Village based on an image as accurate as a google map on March 3, 2022, can be seen in Figure 1. Figure 1 shows that most of the area in Cihanjuang Village has been used by various buildings. Some of the green spaces that still seem to be left are reforestation areas (urban forests), and a few places that are colored yellow are land that is still used as agricultural land.

Figure 1. Land Use Conditions in Cihanjuang Village Viewed from Google Maps

Hydroponics is a suitable solution for farming, especially in urban areas / densely populated areas (1). Hydroponics is a method of growing crops without soil but with nutrient-rich water. The hydroponic method uses materials such as rock wool and coconut fiber as plant growth media. This material does not provide the nutrients plants need, so other forms are required to provide nutrients and oxygen to plants. The provision of nutrients and oxygen is generally made by pumping water rich in nutrients into the hydroponic system, as discussed in (2). Water flow in hydroponic plants is needed for nutritional needs and is also necessary to keep the plants from drying out. Therefore, the function of the pump is essential in the hydroponic system so plants can grow and develop ideally. Land Use Conditions in Cihanjuang Village Seen from Google Maps.

The pumping process requires electrical energy to run according to the needs of hydroponic plants. Using generators for remote areas is not possible because the availability of fuel oil is difficult and expensive, as discussed in (3)(4). Therefore, locally available energy sources, including solar energy, must be available. Photovoltaic-based electricity has begun to increase in recent years. Many big cities in Indonesia have used solar panels for various expansions, such as irrigation machines or electricity production for streetlights. Water pumps for hydroponic plants with multiple capacities can quickly obtain water pumps on the market for both DC and AC pumps. Direct utilization of electric power based on a PV system can use a DC pump.

The feasibility of the proposed integrated PV panel and hydroponic development must assess. In this case, it involves a techno-economic study to ensure the system's feasibility. The study of the technical aspects of the integrated PV panel and the hydroponic system is carried out in a separate paper from this paper. While this paper will focus on the economic part, it will use data on components from the results of the technical aspect study.

This economic study will refer to the three economic indices, PBP, CCP, and ROOR, where these three indices have been able to determine the economic feasibility of the integrated PV and hydroponic systems discussed in (5). The PBP index aims to determine the payback period since the PV and hydroponic system devices operate. The CCP index provides an overview of the system's cash value at the end of the system's life. In contrast, the ROROI index aims to analyze the economics of the system using the rate of return-on-investment criteria, namely the Rate of Return on Investment. The investment costs and operating costs consider cost components. The investment cost component consists of the components' price and the plant's price. While operating costs are the cost of nutrition, maintenance, and labor.

The PV and hydroponic systems that have been built have considered developing hydrophobic plant types. It has been prepared to do second and third modules for other plants that the community needs without additional photo-voltaic system equipment. Flow control is carried out independently for each hydroponic plant module or branching of the flow from the storage tank.

The measurement data of the intensity of solar radiation from the Bandung Geophysics Station shows that the Greater Bandung area has an average solar radiation intensity of around 200 MJ/m^2 in 1 month, as shown in (6). This solar radiation intensity shows that the use of solar panels to convert solar energy into electrical energy is very suitable for implementation. Integrating photovoltaic (PV) and hydroponic systems is a promising solution. There is still uncertainty and little information related to the economic sustainability of the water spinach hydroponic system, especially those integrated with PV, which is the result of a study from (7). Therefore, it is necessary to study the economic aspect of integrated photovoltaic and hydrophilic for Rural Areas in the context of increasing community empowerment activities and rural economic development.

2. METHODS

2.1 Solar Radiation

The PV-Hydroponic system has been installed in RW 14, Cihanjuang Village. The village is included in the Greater Bandung Area, West Java Province. Data on the average solar radiation for the Greater Bandung area during 2021 in (6) is shown in Figure 2.

The Greater Bandung area has average solar radiation of 1.85 kWh/m2/day when converted into energy units. Solar radiation is strongly influenced by the clouds that cover the Bandung area. With a relatively high topography, the average solar radiation during the dry and rainy seasons has relatively high fluctuations, so applying hydroponic technology needs to anticipate plants against rainwater. Thus, hydroponic plants per semi indoors by covering the top of the hydroponic plant.

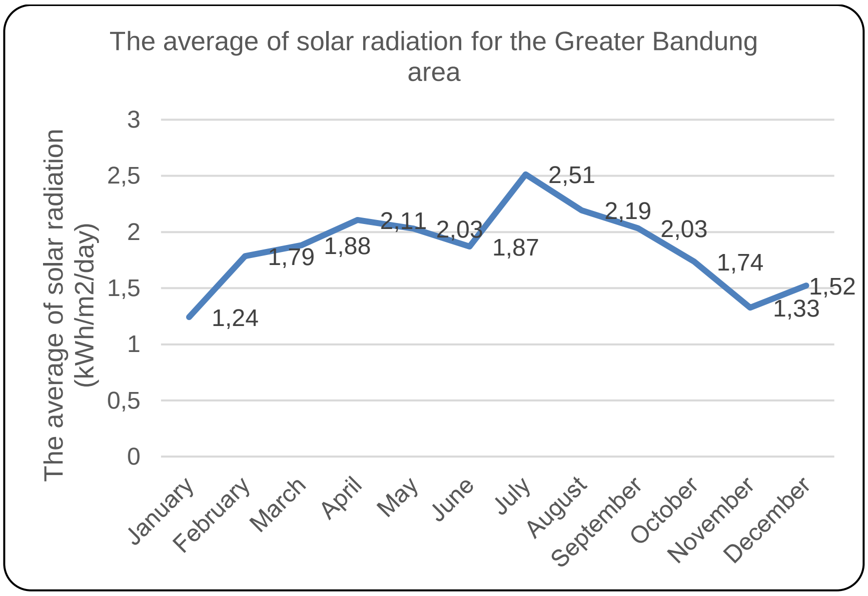

Figure 2. The average of solar radiation for the Greater Bandung area

2.2 PV System

Solar energy can be absorbed by solar cells into direct electrical energy, but a solar cell has a small capacity and a very low voltage. For a larger capacity and higher voltage, the solar cells must be arranged in the form of a grape strand (called a PV Pannel), either in series or in parallel. The series circuit aims to increase the voltage, while the parallel circuit to increase the current is described in (8)-(9). The main material of solar cells is a semiconductor (usually silicon).

The power generated by PV panels is not constant because it depends on sunlight, generally for 6-10 hours/day with an adequate time of 8 hours/day. The PV panel must be equipped with energy storage to produce continuous power. Solar power plants generally consist of 5 main components and auxiliary components (connectors, breakers, conductors, etc.), as shown in Figure 3.

1. PV Panel functions as a producer of electrical energy.
2. Control equipment to control the flow of electric power.
3. The battery functions as a store of electrical energy to ensure the continuity of the power supply.
4. The converter functions as a converter of DC electricity (direct current) to AC electricity (alternating current).
5. The measuring instrument aims to monitor electrical quantities such as voltage, current, and power.

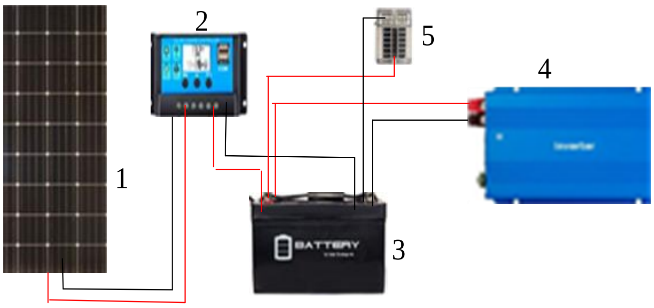

Figure 3. PV System

2.3 Hydroponic System

The limitations of agricultural land in vast open land and the influence of weather have impetus of farming experts to increase agricultural yields through a hydroponic system. The hydroponic system has a minimal area and can be made vertically. This system can be placed outdoors or indoors, where it can adjust indoor weather conditions to suit plants, such as temperature and humidity. However, hydroponic plants must be provided with a continuous flow of water, as shown in Figure 4. Likewise, the provision of nutrients needs to flow regularly, so that plant growth is maximized.

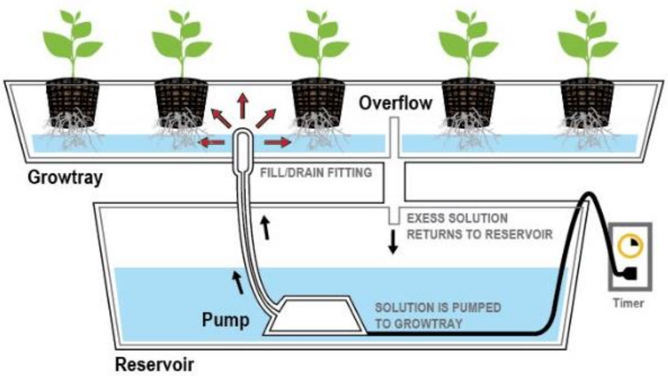

Figure 4. Hydroponic Plant Model
Source: https://hydro-unlimited.com/

The advantages of hydroponic plants over soil plants are fast growth rates and increased yields. Facts on the ground show that plants grow at least 20% faster than gardening on the floor land. In addition, plants will usually produce at least 25% more than soil crops (Figure 5).

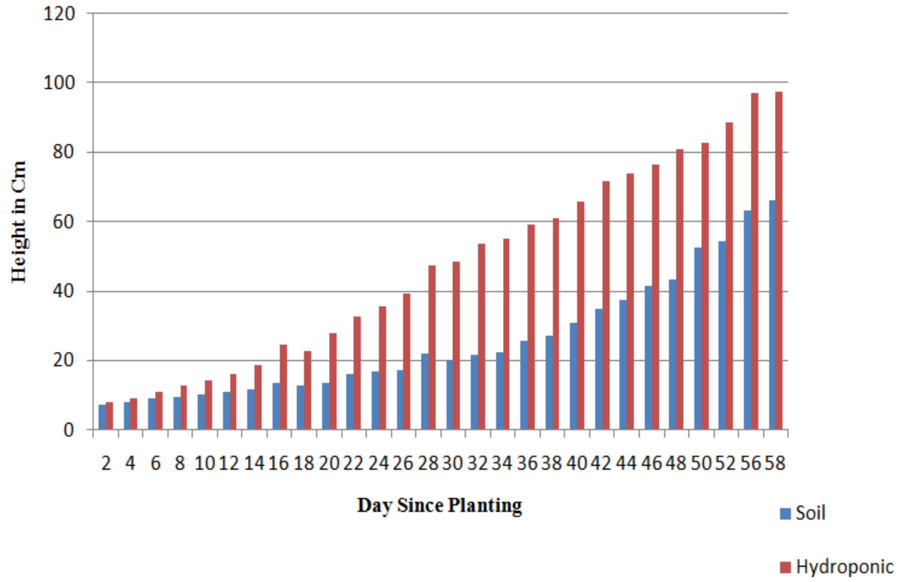

Figure 5. Effect of hydroponic compare soil grown Toronto plants on height
Source: https://www.epicgardening.com/hydroponic-systems

2.4 PV-Hydroponic Integration System

This paper proposes a PV-Hydroponic integration system design shown in Figure 8. PV systems are very limited in the availability of sunlight, so batteries are needed to provide electrical energy at night (Figure 6).

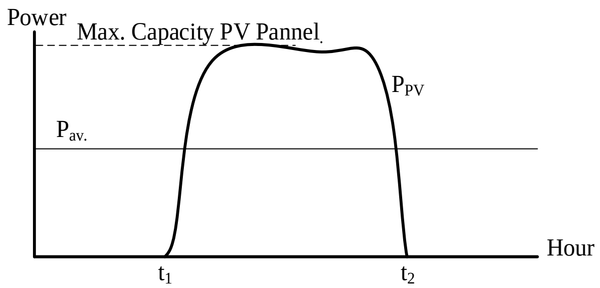

Figure 6. Energy production from PV panels

Figure 7 shows that the role of the PV system must meet the needs of electrical energy during the day for pumping and charging batteries.

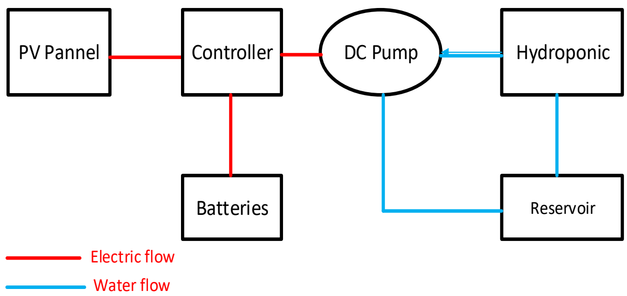

Figure 7. PV-Hydroponic Integration System Block Diagram

The PV system consists of solar panels, solar charger control, and batteries. The PV system works as the main electricity provider for the hydroponic system. In contrast, the battery works as a backup if the solar PV cannot supply electricity to the DC pump (8). With this PV system, continuous availability of electricity needs to be pursued to meet the water needs of hydroponic plants. Meanwhile, the hydroponic system consists of a DC pump and a hydroponic device. The design of the PV-Hydroponic integrated system has technically been carried out in a separate discussion. Used to see the economic value of hydroponic plant production based on PV systems.

2.5 PV-Hydroponic Integration Economic Analysis

The economic analysis of the PV-Hydroponic Integration System was carried out using three criteria discussed by (5)-(10) as follows.

1. Time Criteria
   The Payback Period (PBP) is used to analyze the system's economics using the time criterion. PBP is the time required to return the capital since the scheme started operating (start-up).
2. Cash Criteria
   The cumulative cash position (CCP) is the parameter used to analyze the system's economics using the cash criteria. In general, the CCP will show the system value at the end of the system's life. A system with a CCP value > 1 can potentially provides profit, while a system with a CCP < 1 can be considered unprofitable. CCP is calculated using the equation (1).

$$CCP = \frac{Sum\ of\ all\ positive\ cash\ flows}{Sum\ of\ all\ negative\ cash\ flows} \tag{1}$$

3. Criteria for rate of return on capital modal
   The parameter used to analyze the economics of the system using the rate of return on capital criteria is the Rate of Return on Investment (ROROI). ROROI shows the rate of money generated from the system and is calculated using equation (2).

$$ROROI = \frac{Average\ monthly\ profit}{Initial\ Investment} \tag{2}$$

4. Criteria for production cost
   The parameter used is Energy Production cost (EP). EP shows the comparison of energy production cost to energy consumption as shown in equation (3)

$$EP = \frac{Production\ Cost\ (PC)}{Energy\ Consumption\ (EC)} \tag{3}$$

   PC can be calculated as the sum of all negative cash flows (IDR/months)

3. Result and Discussion

The PV-Hydroponic integration system installed in RW 14, Cihanjuang village, is shown in Figure 4. The hydroponic technique used is the Deep Flow Technique (DFT). The calculation results of the PV-hydroponic system design, which are discussed separately, are shown in Table 1.

Table 1. Calculation results of pump capacity, PV panel and battery

Item	Calculation result		Realization
	Voltage	Power/Ah	Specification
Pump	12 V	25 W	12V/25W
PV	12 V	90 W	2x12v/50Wp
Battery	12 V	78 Ah	2x12V/45Ah or 12V/45Ah+12/35Ah
Frame	5 Stages		5x15 spots
Reservoir	50 Liter		50 Liter
Auxiliary	package		package

The results must adjust the calculation result to the capacity available in the market because the available specifications are not necessarily the same as the calculation results. The selected specifications must be equal to or greater than the calculation results and try to approach the calculation results. For example, for the battery, you can use two 12 V batteries with 45 Ah and 35 Ah for 78 Ah needs. These two batteries will be cheaper than two batteries with the same capacity, which is 2x12 V/45 Ah. The same is true for PV Panels, and it can use two PV panels with a size of 2x50 Wp.

Figure 8 shows the production of hydroponic plants integrated with the system. The hydroponic technique used is the Deep Flow Technique (DFT). The DC pump required is 25 Watts. The water pump's role is to maintain the availability of water and nutrients needed by hydroponic plants. The vegetable production system in Figure 8 can produce 10 kg/month of kale.

Figure 8. Installed PV-Hydroponic Integration System

Meanwhile, the costs incurred for this integration system are shown in Table 2.

Table 2. Cost of PV-Hydroponic Integration System

No.	Equipment	Quantity	Price (IDR)
1	PV System	1	2.000.000
2	Hydroponic System	1	3.000.000
		Total	5.000.000

Savings in electricity costs and the cost of selling kale vegetable products are given in Table 3.

Table 3. Savings on electricity costs and the cost of selling vegetable products

No	Equipment	Amount	Price (IDR)	Total (IDR/ month)
1	Cost saving for electricity	8 Wh/day	1400/kWh	336
2	Kale selling	10 kg/month	40.000/ kg	400.000
		Total		400.336

Assuming the system life is 24 months, the cash flow of the PV-Hydroponic integration system is summarized in Figure 9.

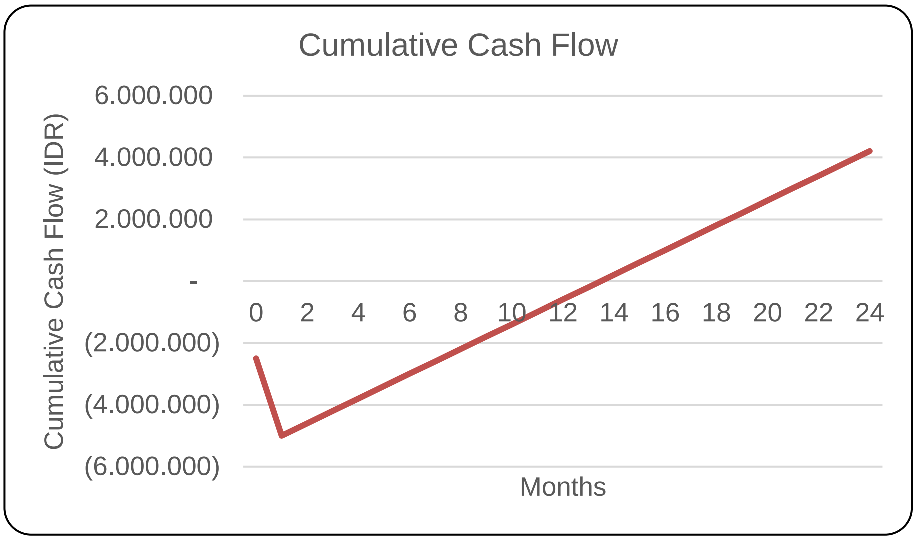

Figure 9. Cash Flow of PV-Hi Integration System

The results of the economic analysis using the three criteria are shown in Table 4.

Table 4. Economics of PV-Hydroponic System Integration

Number of Hydroponic Modules	PBP (month)	CCP	ROROI (%)	EP (IDR/kWh)
1	13.5	1.84	8.01%	868,055.6
2	7.3	3.68	16.01%	434,027.8
3	5.2	5.52	24.02%	289,351.9

The PV-hydroponic integration system is economically feasible based on the three criteria above. With the addition of 2 hydroponic plant modules, the rate of return becomes more attractive (Figure 10). The addition of this module does not require the addition of a photo voltaic system, only by setting the pump workload for 24 hours.

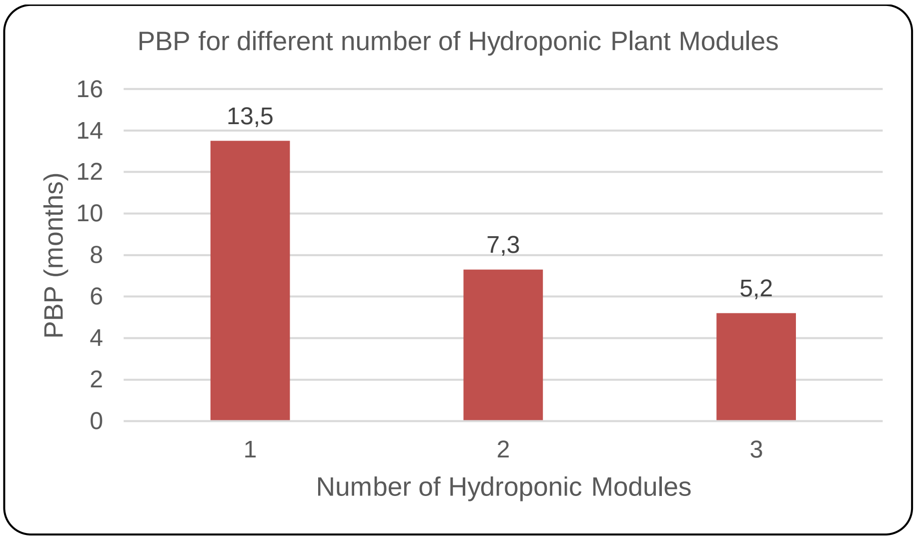

Figure 10. PBP for different number of Hydroponic Plant Modules

Figure 10 shows the economics of the PV-hydroponic system is beautiful if it is carried out in synergy between the needs of vegetable plants for their own needs, as well as for the needs of the community. In the end, the development of the hydroponic plant module is a non-governmental activity in the development of the rural economy.

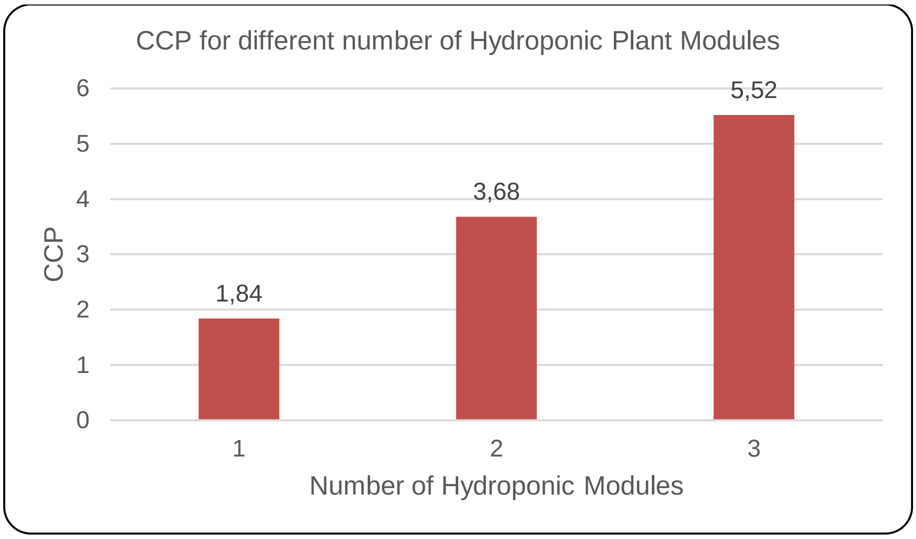

Figure 11. CCP for different number of Hydroponic Plant Modules

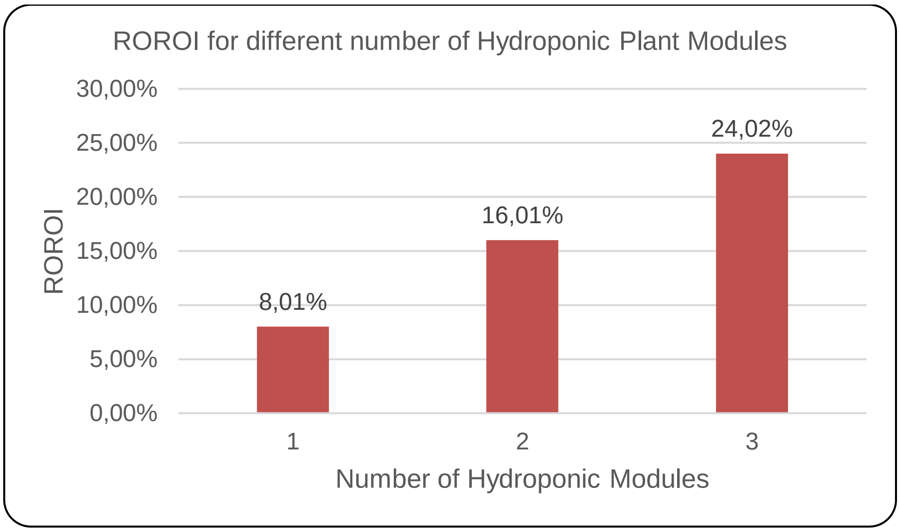

Figure 12. ROROI for different number of Hydroponic Plant Modules

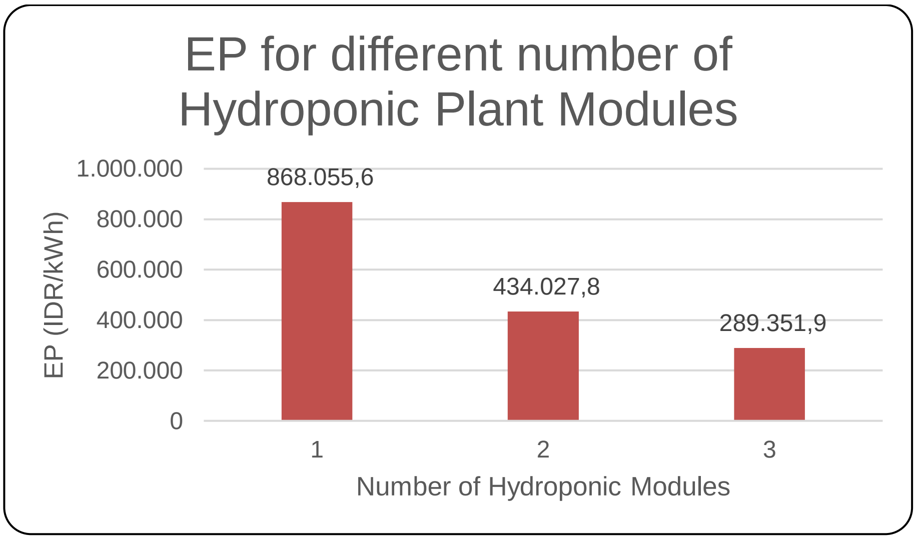

Figure 13. EP for different number of Hydroponic Plant Modules

The development of hydroponic plants is strongly influenced by the readiness of the community to accept and use vacant land. The placement of the hydroponic plant module must take advantage of sunlight from east to west for plant growth. Based on the economic calculation involving components for the investment and operation of the PV-hydrophilic system is shown in Table 1. Table 1 reflects the application of one hydroponic plant module to produce a rate of return on capital (PBP) for 13.5 months.

The profit rate increased significantly with the investment in adding hydroponic plant modules. The decrease can be seen in the rate of return on capital to 7.3 months for adding one module and 5.2 months for adding two modules. It placed plant modules without increasing the investment for the photo voltaic system. There is an additional unit for a photo voltaic system, but it is possible by controlling the loading of the three motors alternately for 24 hours.

The addition of 1 and 2 modules to the system can increase CCP to 3.68 and 5.52, while the ROROI also increase to 16,01% and 24,02%. The EP decrease from 868,055 IDR/kWh to 434,027 IDR/kWh and 289,351 IDR/kWh.

4. Conclusion

Hydroponic plants are an effort to utilize vacant land into productive land with a relatively low area. This plant also supports the development of agricultural technology and rural economic development and increases the capability building of local communities. Economically, the PV-hydroponic integration system has a PBP value of 13.5 months, CCP 1.84, and ROROI 8.01%. With the addition of the second and third hydroponic plant modules, PBP decreased by 6.2 months and 5.2 months, respectively. Likewise, CPP increased from 1.84 to 3.68 and 5.21, respectively. ROROI increased from 8.01% to 16.01% and 24.02% respectively while EP decrease from 868,055 IDR/kWh to 434,027 IDR/kWh and 289,351 IDR/kWh respectively.

References

1. Maucieri Carmelo and Nicoletto C and OE van and AD and HRV and JR, Hydroponic Technologies, *Aquaponics Food Production Systems*, 2019, p. 77–110. doi: https://doi.org/10.1007/978-3-030-15943-6_4
2. Shrestha A, Dunn B, Hydroponics, *Oklahoma State University: Oklahoma Cooperative Extension Service*, 2013.
3. Timmons D, Harris JM, Roach B, The Economics of Renewable Energy, *Global Development and Environment Institute Tufts University*, 2014.
4. Aman LO, Kilo AK, Duengo S, Membangun Kewirausahaan Masyarakat Desa Pone Kecamatan Limboto Barat Kabupaten Gorontalo Berbasis Potensi Desa, *Dedikasi Jurnal Pengabdian Masyarakat*. 2022;15(1):29–36, doi: https://doi.org/10.32678/dedikasi.v15i1.5790
5. Turton R. Analysis, Synthesis, and Design of Chemical Process. Singapore: *Prentice Hall International Series*; 2009.
6. BPS. Data Penyinaran Matahari. Bandung; 2021.
7. Hilman YA, Nimasari EP, Model Program Pemberdayaan Masyarakat Desa Berbasis Komunitas, *ARISTO*, 2018 Jan 1;6(1):45, doi: 10.24269/ars.v6i1.778
8. Weliwaththage SRG, Arachchige USPR, Solar Energy Technology, *Journal of Research Technology and Engineering*, 2020 Jul;1(3):67–75.
9. Kenu E. Sarah, A Review of Solar Photovoltaic Technologies, *International Journal of Engineering Research and Technical Research,* 2020 Jul 18;V9(07), doi: 10.17577/IJERTV9IS070244
10. Gejguš M, Aschbacher C, Sablik J, Comparison of the Total Costs of Renewable and Conventional Energy Sources, *Research Papers Faculty of Materials Science and Technology Slovak University of Technology*. 2016 Jun 1;24(37):99–104, doi: https://doi.org/10.1515/rput-2016-0010