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Off-grid photovoltaic system design for on-board blue swimming crab streamer processing and cold storage: System design and simulation

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Abstract. Blue swimming crab (BSC) catch is considered a highly perishable product; initial on-board processing, including steaming and cool preservation, is necessary to maintain quality. Traditionally, a fire stove conducts the BSC steaming process; this can pose a fire hazard on a wooden boat. Further, the ice-cooled boxes stored the steamed BSC, which could melt and seep into the BSC meat. As an innovation, we could change the BSC steaming process using electronic devices such as electronic stoves and cooling preservation using electric cold storage; both alternatives require electricity as a power source. One electricity source is converting solar energy using solar panel systems (PV). This research aims to design a PV system for the initial on-board processing of BSC and storage, using simulations with PVsyst 7.2 software, to serve as a reference for fishermen, entrepreneurs, and relevant stakeholders. A quantitative method generates wiring diagrams, installation diagrams, and placement plans for the photovoltaic (PV) system and electronic equipment. The technical and economic analyses determined the viability of utilizing the photovoltaic system design. The research result was a complete off-grid PV system design, producing 1740 kWh/year of electricity with a specific yield of 1450 kWh/kWp/year. The investment in the off-grid PV system reaches the break-even point in 2043, with a profit of 68,534 IDR. This off-grid PV system design can supply the electricity needed for electronic equipment used in the initial on-board processing of BSC catch.

1 Page layout

1.1 Blue Swimming Crab (BSC) Fisheries

Indonesia is one of the leading producers of Blue Swimming Crab (BSC) products [1]. As a fishery commodity, BSC has a high economic value [2]. Figure 1 shows a picture of the BSC.

BSC holds significant importance as a fishery commodity in Indonesia. Especially along the northern coast of Java (Pantura) [3], many residents work as BSC fishermen. Some fishermen operate for only one day, while others operate for more than one day. To prevent the BSC meat from spoiling, the fisherman executes initial processing by steaming it and storing it in cold storage [4]. Steaming uses a steamer heated with an LPG stove, and cold storage uses boxes with ice coolers. These two initial handling stages have adverse effects because BSC fishing boats made of wood have a high fire hazard [5] if there is an LPG stove leak.

Fig. 1. BSC catch.

Meanwhile, boxes with ice coolers can quickly melt, especially on BSC fishing boats that operate for more than one day. The infiltration of ice water during storage can affect the quality of BSC meat [6], which can decrease the quality of the BSC. Figure 2 shows the initial handling equipment for BSC during observation.

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Fig. 2. Initial processing equipment for BSC, A) Steaming steamer, and B) Cold storage box.

1.2 Photovoltaic system

They expect to address the issues faced during the initial handling of the BSC by using electronic devices such as induction electric stoves and freezers. However, the use of electronic devices requires electrical energy to operate. Using innovative and sustainable energy (EBT) methods can produce electrical energy. Indonesia has great potential for EBT. EBT aims to fulfill the national primary energy mix strategy [7]. Solar energy is one form of EBT that is easy to employ for several advantages. Solar energy is abundant, inexhaustible, and environmentally friendly [8]. As a renewable source, solar energy is unlimited and sustainable [9]. Solar energy can be converted into electrical energy using a photovoltaic (PV) system [10]. The solar panel is the main component of a PV system. The functions that facilitate converting solar energy into electrical energy are described in reference [11]. When sunlight hits the photovoltaic cells in the solar panels, the electrons within the semiconductor material become excited and begin to move [12], generating direct current (DC) electricity. Java Island shows high levels of solar energy, with global horizontal irradiation (GHI) potential ranging from 5.40 to 5.43 kWh/m² in various regions [13]. High solar energy capacity for development and utilization makes GHI at Java Island suitable for small-scale applications, such as on BSC fishing boats. PVsyst software designs a PV system that converts solar energy into electrical energy [14]. To use PVsyst software to analyze the power load requirements. In this research, we use PVsyst software to design a PV system to manage BSCs on fishing boats.

The photovoltaic (PV) system is crucial for converting solar energy into electrical energy [15]. Critical elements of a PV system include solar panels, controllers [Solar Charge Controller (SCC) and inverter), and batteries [16]. Additional components such as cables, Miniature Circuit Breakers (MCB), electrical terminals, and contactors support this system. Solar panels convert solar energy into electrical energy through the photovoltaic process. Solar panels are typically installed on the roofs of houses and commercial buildings [17] or placed in locations exposed to direct sunlight, such as the roofs of boats. The PV system produces electrical energy that solar irradiation, particularly GHI, greatly influences [18]. Various factors affect a GHI, including latitude, altitude, seasonal weather conditions, and air pollution [19]. Therefore, the amount of electrical energy generated is highly dependent on the location of the PV system installation.

1.3 Blue Swimming Crab Initial Handling Devices

With the design of the PV system for the initial handling of BSCs, fishermen will use it to operate electronic devices for steaming, cold storage, and lighting that can help with visibility on the BSC fishing boats. The requirements for these electronic devices are as follows:

a. Heat the water in the steamer using an induction electric stove. The induction stove generates heat that converts the water in the steamer into steam at a temperature between 80°C and 90°C. This steam is used to steam the BSC arranged in the pot.
b. Freezer to cool the BSC stored inside. The freezer gradually lowers the temperature in the compartment and the BSC to between -4°C and 0°C or to the specified freezer temperature between -11°C and -13°C.
c. Light-emitting diode (LED) lamps are semiconductor devices that emit light when an electric current passes through them. The LED lamps used will provide lighting on the BSC fishing boats. LED lamps use energy more efficiently compared to other types of lighting.

1.4 Research purposes

This study aims to design a PV system simulation using PVsyst 7.2 software for the preliminary management of BSC on-board. It will use a quantitative method, creating wiring diagrams, installation diagrams, placement on the boat, and technical and economic analysis to determine the feasibility of the PV system design. This research will help fishermen, entrepreneurs, and relevant stakeholders utilize solar energy to power BSC systems on boats. This approach will maintain the quality of BSCs, reduce greenhouse gas emissions from carbon gases, and contribute to mitigating global warming.

2 Materials and methods

2.1 Research sample location

This research was conducted and simulated at one of the stock assessments and BSC fishing locations of the Indonesian BSC Business Association (APRI) on the island of Java. Java has five APRI stock assessment and BSC fishing locations, specifically at Cirebon, Pemalang, Pati, Rembang, and Gresik [20]. The research sample was taken in the Rembang location because Rembang has BSC fishermen who operate for more than one day using boats larger than 5 GT.

Rembang, located on the northern coast of Java Island, experiences high GHI throughout the year. Additionally, the GHI in Rembang is like that of other BSC-producing areas along the north coast of Java, making the simulation results applicable as a reference for fishermen in another region. The simulation conducted on BSC on-board under 20 GT in Rembang aims to enhance the local BSC industry. Fishermen in Rembang generally use LPG for steaming BSCs, but it is expensive and has negative environmental impacts. The coordinates for the Rembang area are 6.708° South Latitude and 111.341° East Longitude. Figure 3 shows the map of the Rembang area.

Fig. 3. Map of the Rembang Area (Source: Google Maps).

This location was selected based on the operational characteristics of the fishermen in Rembang, making it ideal for simulating the PV system design for BSC fishing operations lasting more than one day.

2.2 Research Methods

This study can use PVsyst 7.2 software to produce designs and data that were analyzed both technically and economically to assess the feasibility of the off-grid PV system design for use on crab fishing boats. The research workflow diagram appears in Fig. 4.

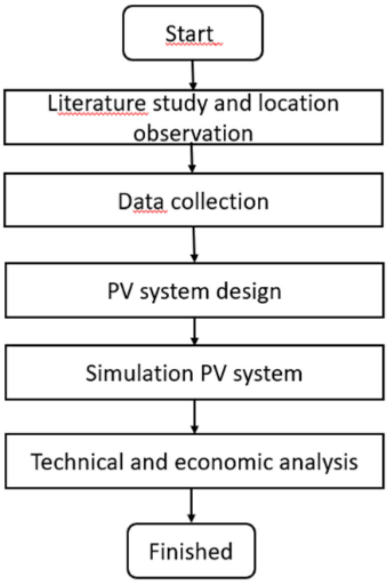


Fig. 4. The research workflow diagram.

The following is an explanation of the workflow diagram used in this study. A literature review involves reading and searching existing writings to identify, evaluate, and synthesize findings from previous research relevant to the topic and research questions regarding the PV system. To gather additional data for the study, researchers directly observe objects. Data collection involves recording data from the PVsyst 7.2 software to support the research. The PV system design begins with determining the necessary components and creating installation and wiring diagrams that match the initial requirements. The PVsyst 7.2 software simulates the PV system to generate performance data for the designed system. Technical analysis involves evaluating the performance data of the PV system produced from the PVsyst 7.2 simulation. The designed PV system is analyzed technically to assess its feasibility, leading to conclusions drawn from the research. To conduct an economic analysis, input investment cost data, energy yield estimates, and economic parameters into PVsyst 7.2, which then produces the economic feasibility results of the designed PV system.

2.3 Analysis

This stage involves designing the PV system, including power load, main components used, installation diagrams, wiring diagrams, and power output calculations. Power load refers to the amount of power needed to operate electrical devices. Several factors, including the tilt angle of the solar panels, panel orientation, temperature, and the performance of PV system components, also influence the performance of the PV system in addition to GHI [21]. Various factors, like solar irradiation, ambient temperature, cell temperature, tilt angle, dust accumulation, and shading, significantly affect the performance of the PV system [22]. The comparison of the PV system's electrical power generation to the energy losses during its operation under normal conditions indicates the system's technical feasibility. The efficiency of solar panels, temperature, and inverter efficiency can influence losses [23]. Evaluate the economic feasibility of a PV system design using PVsyst 7.2 software, considering factors that influence the financial value of the design. The key factor affecting the economic analysis is the initial capital investment. The initial capital outlay primarily determines the economic analysis. The initial investment refers to the upfront expenses of acquiring the necessary components and installing the PV system. Next are the operational and maintenance costs, which require annual expenditures for the system.

Additionally, during an economic analysis using PVsyst software, it is crucial to consider economic indicators such as Net Present Value (NPV). NPV reflects the net value from the first investment to the last year of PV system operation. The Internal Rate of Return (IRR) refers to the anticipated rate of return derived from the investment in the PV system. The Payback Period is the time it takes to recover the initial investment in the PV system by assessing the savings or income generated. Finally, the Levelized Cost of Energy (LCOE) refers to the mean expense of generating energy throughout the operational lifespan of the PV system.

3 Results and discussion

3.1 Daily electrical power load calculation

We must take several steps to ensure the quality of the BSCs. The initial processing of BSCs is crucial to ensuring their quality remains intact until they reach the consumer. The initial processing conducted on the BSC fishing boats consists of steaming and cold storage of the BSCs. An induction stove can achieve steaming by harnessing electrical energy for the initial processing of BSCs. A freezer keeps things cold, and LED lights are used at night to light the boat. Table 1 shows the power load requirements for the initial BSC processing simulation.

Table 1 shows that the designed PV system must manage the peak load when the induction stove, freezer, and lighting are all operating simultaneously, with a load of 760 Watts, and must be able to supply a total electrical load of 4520 Watts in one day. However, considering the operational hours of the BSC initial processing devices, the peak load occurs only when the induction stove and freezer operate simultaneously at 9 a.m. and 1 p.m., with an electrical load of 740 Watts.

Table 1. Daily peak load and total daily power load requirements for the simulation of initial processing of BSCs.

Device	Quantity	Power (Watts)	Usage time	Peak load (Watts)	Total Daily Power Requirement (Watts)
Induction electric stove	1	600	09.00 A.M.-10.00 A.M. 01.00 P.M.-02.00 P.M.	600	1200
Freezer – Cold Storage	1	140	06.00 A.M.-11.30 A.M., 00.00 P.M.-05.30 P.M., 06.00 P.M.-11.30 P.M. 00.00 A.M.-05.30 A.M.	140	3080
LED lamp	2	10	05.30 P.M.-05.30 A.M.	20	240
				760	4520

3.2 Environmental Data for the Rembang Location

Table 2. Monthly environmental data for the Rembang location.

Month	Global horizontal irradiation	Year to year variability	Horizontal diffuse irradiation
	kWh/m^2/mth	%	kWh/m^2/mth
January	143,0	5,5	81,8
February	150,2		80,3
March	154,2		84,6
April	166,7		75,6
May	156,2		67,8
June	150,9		64,4
July	164,1		64,9
August	177,0		74,6
September	178,9		78,9
October	186,6		91,3
November	165,0		89,3
December	163,1		89,9
Yearly	1955.6		943,3

Environmental data for the Rembang location, with coordinates obtained through PVsyst 7.2 software using Meteoronorm 8.0 data, consists of monthly data for various parameters such as Global Horizontal Irradiation, Year-to-Year Variability, Horizontal Diffuse Irradiation, Temperature, Wind Velocity, Linke Turbidity, Relative Humidity, and Horizontal Year-To-Year Variability. Tables 2 and 3 show the environmental data from the simulation results.

Table 3. Monthly environmental data for the Rembang location.

Month	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	^{0}C	m/s	[-]	%
January	27,4	1,79	4,580	81,6
February	27,3	1,80	4,540	82,4
March	27,7	1,29	4,637	81,1
April	27,9	1,31	4,705	81,0
May	28,6	1,60	4,357	75,9
June	27,8	1,70	4,315	74,6
July	27,9	2,00	4,366	70,0
August	27,9	2,19	4,776	67,2
September	28,2	2,09	5,156	68,1
October	29,1	1,79	6,543	69,1
November	28,4	1,30	6,392	76,9
December	27,9	1,19	5,198	80,3
Yearly	28,0	1,70	4,965	75,7

3.3 System types

PV systems used worldwide consist of three types: off-grid, on-grid, and hybrid [24]. The design of the PV system based on its type is shown in Fig. 5. The off-grid type, or standalone system, is a standalone PV system typically fitted with storage batteries and operates independently from the grid. The off-grid PV system is used in remote locations or places without access to an electricity grid, such as in the middle of the sea. The on-grid type connects directly to the grid but lacks batteries. The hybrid type combines both off-grid and on-grid PV systems. PV system chose the off-grid type to simulate the PV system for the initial process of BSCs using PVsyst 7.2 software.

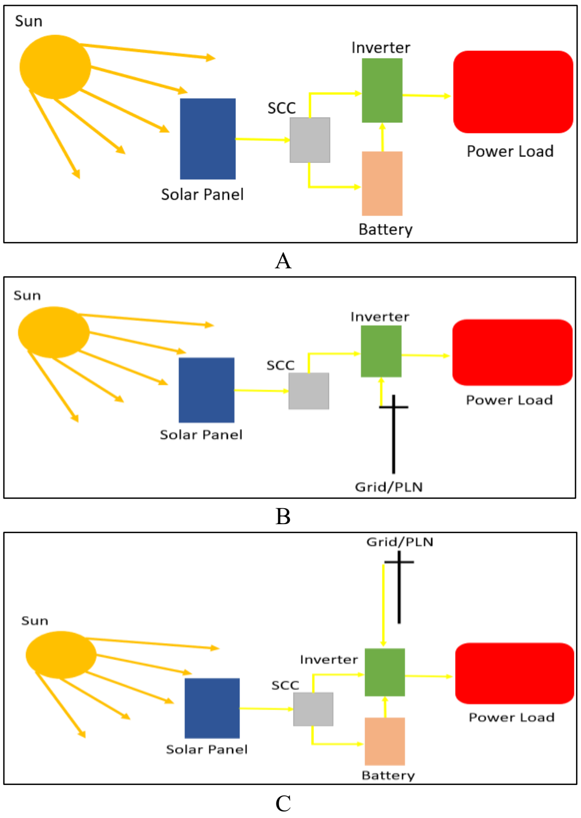


Fig. 5. PV system design, A) Off-grid, B) On-grid, and C) Hybrid.

3.4 System design

Initial design processing of BSC using the Off-Grid PV system type. Assembling several components forms an off-grid PV system. The off-grid PV system in the simulation using PVsyst 7.2 software comprises three essential parts, each consisting of four primary pieces. The solar panel converts photon energy from solar radiation into electrical energy. The created electrical energy by the solar panel is affected by various elements, including solar radiation, temperature, shade, panel tilt angle, and panel orientation [25]. The solar panels are installed on a fixed plane with a tilt angle of 30° and an azimuth angle of 0°, facing north. The Yearly Irradiation Yield data, including Global Horizontal Irradiation, Year-To-Year Variability, Transportation Factor FT, Loss concerning optimum, and Global on-collector plane obtained from the simulation, are shown in Table 4.

In the simulation using PVsyst 7.2 software, the controller consists of a SCC and an inverter. Therefore, the controller functions as a combination of the SCC and the inverter. The SCC regulates the electrical current or voltage received from the solar panels and controls the current or voltage directed to the inverter or directly to the current electrical consumption. The SCC also manages the current and voltage from the solar panels to the battery to prevent overcharging. The inverter converts the DC electricity or voltage from the SCC and battery into alternating current (AC) or voltage, making it usable for electrical loads that require AC or voltage. The SCC supplies current and voltage to the battery, which stores the energy for use when the solar panels cannot generate electricity.

Table 4. The main component of PV system simulation.

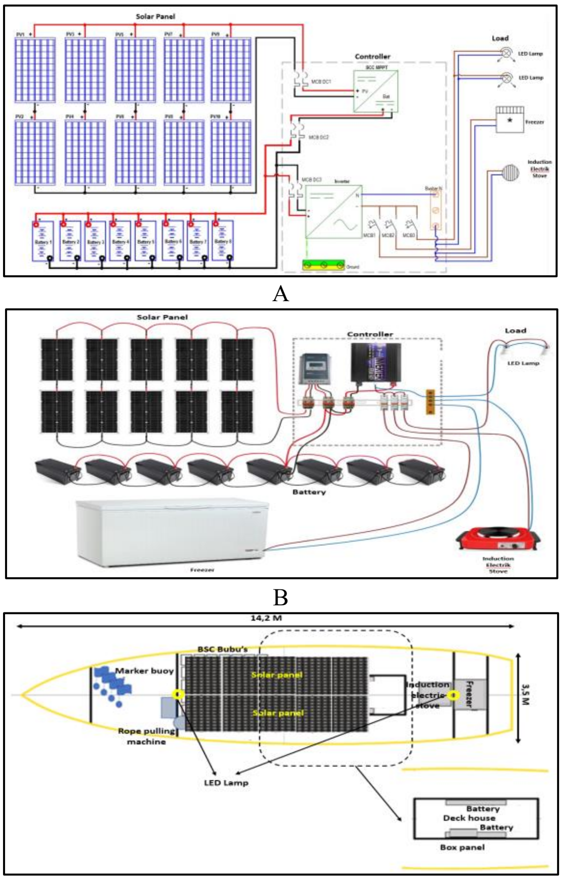
Component	Specification	Wide	Installation	Simulation
Solar panel				
Solar panel	Total: 10, Material: Si-Mono, Vmpp: 60° (12,6 V), Voc: 20° (21,1 Volt), Voltage: 12 Volt, Power: 120 Watts Peak (Wp)	9 m^2	5 string, 2 modules	Power: 1200 Wp, Average daily energy: 4,33 kWh
Controller				
SCC	Total 1: Voltage: 12 Volt, Current: 70 Ampere	-	-	Power: 1000 Watts, Operating voltage: 17-245 Volt, Input max voltage: 250 Volt, Input to battery: 12 Volt, Current: 70 Ampere
Inverter	Total: 1, Power: 1000 Watts, Voltage: 12 Volt	-	-	
Battery				
Battery	Total: 8, Material: Pb (Lead-acid), Voltage: 12 Volt, Power: 100 Ampere hours (Ah)	-	8 parallel	Capacity: 800 Ah, DOD: 80 %, Energy storage: 7,68 kWh, Real energy storage: 6,829 kWh, Temperature: 20° C, Weight: 356 kg

The induction electric stove is used twice a day at 09:00 A.M. for one hour and at 01:00 P.M. for one hour, with 600 Watts, resulting in a total daily power requirement of 1200 Watts. The freezer or cold storage is used throughout the day in 4 intervals, totaling 22 hours per day, with a power of 140 Watts, resulting in a daily power requirement of 3080 Watts. Two LED lamps, each with a power of 10 Watts, are used for 12 hours, from 05:30 P.M. to 05:30 A.M., resulting in a daily power requirement of 240 Watts. The off-grid PV system design must meet the minimum power requirements of the electrical load with a peak load of 760 Watts and a total daily power requirement of 4520 Watts for all devices. Fluctuating daily power loads can affect the performance and reliability of a PV system, especially concerning the storage of electrical energy in batteries. The electrical energy produced by an off-grid PV system relies solely on solar radiation. Therefore, only a minimal amount of energy can be stored in the battery when the load directly uses electrical from the SCC to the inverter, significantly during activities like steaming BSC; this raises concerns that the battery may need help to back up the necessary load requirements at night or in bad weather.

However, the number of solar panels and batteries must be sufficient to meet the power needs when sunlight is obstructed for extended periods, preventing the solar panels from generating energy. Table 4 shows the main components used in the simulation.

3.5 Off-Grid PV System Design and Placement

Based on the simulation design of the main components, the wiring diagram, installation diagram, and layout for placing the main components and electrical devices for the initial processing of BSCs on the boat. Figure 6 illustrates the BSC boat, based on a Bugisan boat weighing less than 20 GT, with a length of 14.2 meters and a width of 3.5 meters, for the simulation.



A

B

C

Figure 6. Off-grid PV system design and placement, A) Wiring Diagram, B) Installation diagram, and C) Placement design on the Boat.

Based on Figure 6, the operation of the PV system begins with the solar panel, which converts solar energy into electrical energy through the photovoltaic process. Next, the electrical power, consisting of DC voltage and current, is directed to the controller. The controller includes an SCC and an inverter. The inverter converts the DC voltage and current into AC voltage and current, supplying them to the load, including an induction electric stove, freezer, and LED lights.

3.6 Simulation

The simulation will be performed using PVsyst 7.2 after inputting the supporting data from Meteoronorm 8.0, allowing PVsyst 7.2 to produce the off-grid PV system simulation output. This supporting data includes GHI, temperature, wind speed, solar panel orientation, principal components, and electronic device data for the initial processing of BSCs, which constitutes the daily load. Initial data, including orientation, user needs, and system requirements, is entered into PVsyst 7.2. This data runs simulations that provide system production values, specific production, performance ratio, normalized production, array losses, and system losses. Table 5 shows the results of these simulations for the off-grid PV system design in the initial BSC processing.

Table 5. Simulation data results of the off-grid PV system.

System Overview	Result
System Kind	Stand Alone System with Batteries
System Production	1740 kWh/yr
Specific Production	1450 kWh/kWp/yr
Performance Ratio	0,678
Normalize Production	3,54 kWh/kWp/day
Array Losses	1,46 kWh/kWp/day
System Losses	0,22 kWh/kWp/day

The off-grid PV system simulation design can produce data on external factors such as irradiance at 800 W/m², incidence angle of 40°, beam/global ratio of 80%, environmental temperature of 20°C, and wind speed of 1 m/s. Figure 7 shows the graph of array loss under 800 W/m² irradiation, resulting in an array Pmpp of 778 Watts and a global loss of 17.5%.

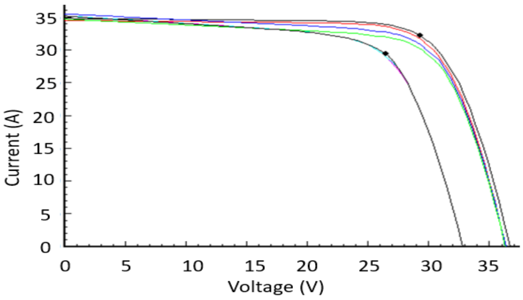


Fig. 7. Array losses and system losses of the off-grid PV system (Source: Simulation with PVsyst 7.2).

Based on Figure 7, the black line represents the module temperature at 25°C, the red line represents module quality loss, the purple line represents module mismatch, the green line represents IAM, the pink line represents module temperature at 52.0°C, the blue line represents wiring resistance, and the brown line represents series diode loss.

Tables 6 and 7 present the simulation results showing the environmental impact on the off-grid PV system using PVsyst 7.2.

Table 6. Simulation data results of the environmental impact on the off-grid PV system 1.

Month	**GlobHor**	**GlobEff**	**E_Avail**	**EUnused**
	kWh/m^2	kWh/m^2	kWh	kWh
January	143,0	108,5	104,2	0,00
February	150,2	123,7	118,1	0,00
March	154,1	140,0	131,9	0,01
April	166,6	170,5	158,9	14,92
May	156,2	174,9	162,3	18,96
June	150,9	176,1	164,5	19,77
July	164,1	189,9	176,9	28,06
August	177,0	189,2	176,3	24,98
September	178,9	171,6	160,0	17,05
October	186,6	159,6	149,4	4,65
November	165,0	128,0	122,0	0,01
December	163,1	119,7	115,3	0,01
Yearly	1955,6	1851,9	1729,7	128,44

Table 7. Simulation data results of the environmental impact on the off-grid PV system 2.

Month	**E_Miss**	**E_User**	**E_Load**	**SolFrac**
	kWh	kWh	kWh	ratio
January	34,37	106,5	140,9	0,756
February	14,25	113,0	127,2	0,888
March	13,13	127,7	140,9	0,907
April	2,67	133,6	136,3	0,980
May	2,74	138,1	140,9	0,981
June	0,00	136,3	136,3	1,000
July	0,00	140,9	140,9	1,000
August	0,00	140,9	136,3	1,000
September	0,00	136,3	140,9	1,000
October	0,00	140,9	140,9	1,000
November	13,31	123,0	136,3	0,902
December	27,93	112,9	140,9	0,802
Yearly	108,40	1550,2	1658,6	0,935

To simulate the off-grid PV system design for initial BSC processing of BSCs on the boat using PVsyst 7.2 software, an economic analysis was also conducted to determine the initial costs for installing all components of the off-grid PV system, including component purchase with installation costs, and analysis aimed to determine how quickly the investment costs can recover and to understand the return on investment (ROI). Efficiency and productivity of the Off-Grid PV system design are also assessed by comparing the potential energy production from the solar panels with the incurred costs, ensuring that the investment generates enough energy to meet needs and provide a return. The design also considers maintenance and system lifespan to ensure that the Off-Grid PV system will last long-term. Analyzing the economic aspects of the Off-Grid PV system design for crab processing on the boat will help fishermen, entrepreneurs, and stakeholders decide whether they can broadly and directly implement the design on BSC fishing boats. The initial investment in the Off-Grid PV system design using PVsyst 7.2 software encompasses accessories, solar panels, controllers, batteries, combiner boxes, wiring, and installation procedures. Table 8 shows the initial investment requirement.

Table 8. Inihtial investment cost of the solar panel system.

Item Name	**Quantity**	**Unit**	**Total (IDR)**
Accessories	1	package	6.518.538
Solar panel	10	unit	3.536.416
Controller	1	pakcage	2.064.578
Battery	8	unit	9.345.000
Combiner box	1	unit	688.860
Wiring	1	package	2.188.973
Installation	1	package	3.438.284
	Total		27.780.649

Perform the economic analysis using PVsyst 7.2 software; several variables are required, including repair cost, battery replacement, project lifetime, inflation, discount rate, income tax, dividends, depreciation period, and depreciation coefficient. Table 9 shows data for these variables.

Table 9. Economic analysis variables for the Off-Grid PV system.

Variable	**Quantity**
Repairs	10%/tahun
Battery replacement	25%/tahun
Project lifetime	20 tahun
Inflation	2,84%/tahun
Discount rate	5%/tahun
Income tax (Pph)	1,5%/tahun
Dividends	2%/tahun
Depreciation period	20 tahun
Depreciation coefficient	5

The initial investment costs and designed variable data are then input into PVsyst 7.2 software to obtain the financial summary, which includes Installation Costs (CAPEX), which consists of Total Installation Cost, Total Yearly Cost, and Depreciable Asset. Financing: This includes Own Funds, Subsidies, Loans, and Total Financing. Expenses: This includes Operating Costs (OPEX), Loan Annuities, Total Expenses, and LCOE (Levelized Cost of Electricity). Return on Investment (ROI): This includes Net Present Value (NPV), Payback Period, and Return on Investment (ROI). Table 10 shows all financial summary data.

There is no specific research on using off-grid PV systems for the initial processing of BSC, making this study highly representative and worth pursuing in prototype development. However, in 2023, Setiyobudi et al. reviewed the application of hybrid/electric propulsion systems between PV systems and wind turbines for BSC fishing ships operating for seven days in the Java Sea [26]. Setiyobudi explores how to apply renewable energy sources to meet electricity needs on board and assesses their economic impact. The electrical devices required include lighting, GPS, radio, cooling boxes, and BSC cookers, with a total power load of 17.204 Watts per day. The PV and wind turbine system reviewed generates 22.960 Watts per day. The review results indicate that the hybrid/electric propulsion system design faces significant challenges. Based on the serial configuration of the power topology, preliminary calculations show a total load requirement of 293 kWh, with a battery requirement of 240 units, equivalent to 3,4 tons of Life-Po4 type, plus other components. The initial investment is approximately USD 21.084.

Table 10. Financial summary.

Installation Costs (CAPEX)	
Total Installation cost	64.324.237 IDR
Total yearly cost	10.973.362,23 IDR/year
Depreciable Asset	43.418.899 IDR
Financing	
Own Funds	64.324.237 IDR
Subsidies	0.00 IDR
Loans	0.00 IDR
Total Financing	64.324.237 IDR
Expenses	
Operating Costs (OPEX)	10.973.362,23 IDR/year
Loan Annuities	0.00 IDR/year
Total Expenses	10.973.362,23 IDR/year
LCOE (Levelized Cost of Electricity)	9.937,84 IDR/kWh
Return on Investment (ROI)	
Net Present Value (NPV)	68.634,28 IDR
Payback Period	20.0 years
Return on Investment (ROI)	0.1%

3.7 Technical analysis

Weather conditions, the angle of the sun, and atmospheric conditions influence the intensity of GHI throughout the year. When the weather is clear, the intensity of GHI is high, allowing the PV (photovoltaic) system to produce much electrical energy. However, during the rainy season and overcast skies, GHI intensity is low, leading to reduced electrical energy production from the PV system, and it may even reach zero.

Environmental temperature also affects the electrical energy production of the PV system. High temperatures can decrease the voltage output, resulting in suboptimal energy production. High wind speeds can lower the temperature, allowing the PV system to produce energy more efficiently. However, very high wind speeds pose a risk to the structural integrity of the solar panels mounted on the boat, potentially causing them to collapse. Low wind speeds can lead to higher environmental temperatures, reducing the efficiency of energy production. High humidity can cause condensation on the surface of the solar panels, which decreases their efficiency.

The main findings of this research are the design of the off-grid PV system for the initial processing of BSCs, and the off-grid type chosen due to its energy production and placement advantages. An off-grid PV system can generate electricity without being connected to the grid. It offers benefits for various applications, including Mari. It provides advantages for several uses, such as time transport and remote areas [27]. This system is easy to build on a small scale and optimizes the utilization of unlimited and free solar energy with low operational and maintenance costs, thus reducing operational expenses.

Additionally, off-grid PV systems do not produce air pollution like carbon emissions, making them environmentally friendly compared to fossil-fuel-based power plants, such as gasoline-powered generators. Figure 6 and Table 5 show that we used monocrystalline 120 WP and 12 Volt solar panels for the simulation. Manufacturers make monocrystalline panels with a high percentage of silicon, making them more efficient than polycrystalline panels. When comparing solar panels of the same power, monocrystalline panels typically have a smaller surface area than polycrystalline panels [28]. The solar panel comes in this standard size, which is easy to find on the market. It also makes system math easier, which makes it easier to choose the suitable controller and battery. Because monocrystalline panels are small and proper for small projects, BSC fishermen can easily add more panels to increase the system's power.

The SCC and the inverter are combined to form a controller in the PVsyst 7.2 software. The SCC regulates the passage of electricity from the solar panels to the battery, thereby preventing overcharging or deep discharging, which could damage the battery. It also directs the current to the inverter. The SCC chosen for the simulation has specifications of 12 Volts and 70 A to match the voltage of the solar panel, maintaining balance when the current produced by the solar panel is high, thereby ensuring flexibility and safety in the PV system. The inverter converts the DC electricity generated by the solar panels into AC (alternating current) voltage and current, which directly operates loads such as electronic devices for initial BSC processing. The inverter selected for the simulation has specifications of 1000 Watts and 12 Volts, which are by the peak capacity of only 760 Watts and the solar panel voltage of 12 Volts. Additionally, inverters with these specifications are affordable.

The solar panels generate electricity, which the SCC stores in the battery. BSC fishermen can use this stored electricity when sunlight is unavailable, such as at night or during cloudy weather. The battery stores electricity as DC voltage and current, so the inverter converts the electricity from the battery to AC voltage and current. The battery chosen for the simulation has specifications of Pb (Lead-Acid), 100 Ah, and 12 Volts due to its low cost and availability compared to other materials and to match the system voltage of 12 Volts.

In addition to these primary components, a PV system necessitates ancillary components, including a mounting system and electrical circuits, to ensure the system's safety. The supporting parts were responsible for transmitting electricity from the inverter to the load, including BSC processing equipment and the system's protection from potential hazards, such as voltage fluctuations or short circuits. The sustaining components include cables, MCB (Miniature Circuit Breaker), and grounding rods. The mounting system supports the solar panels on the BSC boat and positions them at an optimal angle to capture solar energy. Steel or aluminium comprises the mounting system.

Furthermore, an electrical enclosure is required to accommodate the controller, MCB, and grounding rods. While the PVsyst software does not incorporate these supporting components, the necessary materials for their construction are accounted for in the initial investment costs.

The output power and losses of a PV system designed using PVsyst 7.2 can be generated by inputting several factors, such as environmental data from the simulated location, and determining the system design. Based on the data in Table 5, the amount of electricity produced by the solar panels is 1740 kWh/year, with a specific production of 1450 kWh/kW/year. The usable electricity from the Off-Grid PV system is only 1450 kWh/kW/year. The Performance Ratio (PR) of this Off-Grid PV system is 0.678. PR is a reference for measuring the efficiency of a PV system in converting solar energy into electricity. PR is a crucial metric to assess PV system performance, but various factors, such as cable losses and inverter inefficiencies, influence it. However, temperature can significantly impact PR [29]. A PR value of 0.678 means that the Off-Grid PV system can convert 67.8% of the theoretical solar energy received by the solar panels based on solar irradiance. The standardized production value is 3.54 kWh/kWp/day. Standardized production is vital for understanding the PV system's performance by adjusting the electricity production data under normal conditions.

The simulation results of the Off-Grid PV system show that array losses occur. Array losses refer to the reduction in the efficiency or overall performance of the solar panel array due to various factors, including mismatch losses, ohmic losses, temperature losses, soiling losses, shading losses, and DC to AC conversion losses. Array losses indicate the Off-Grid PV system's maximum efficiency and optimal power during operation [30]. The array losses in the simulated Off-Grid PV system are 1.46 kWh/kWp/day. System losses for the Off-Grid PV system are 0.22 kWh/kWp/day. System losses encompass all energy losses throughout the PV system, from the solar panels to the electrical load point, as well as component lifespan and performance degradation over time. Figure 7 is a characteristic graph of a solar panel array showing the relationship between current and voltage, which results in losses from the PV system design. The graph displays data for the array's maximum power (Pmpp) at 942 Watts, generated by the solar panels at a temperature of 25°C.

Module Quality Losses is 1.5%. Module mismatch or the loss due to panel mismatch at a specific temperature is 2.0% when the temperature reaches 45°C. IAM (Diffuse, beam 40°) shows a loss of 2.2% due to the angle of sunlight not being perpendicular to the module. Module temperature, where the power loss due to the module temperature exceeding 52°C, reaches 12.5%. Wiring resistance or power loss due to cable resistance more significant than one mOhm reaches -0.1%. Serie Diode Loss V is 0.7, where V is the power loss due to voltage drop across the series diode, which is 0.8%. The result shows that the maximum power generated by the solar panels is 778 watts after accounting for all losses, with a total loss of 17.5%. The electricity generated in the Off-Grid PV system simulation using PVsyst 7.2 software is 3.54 kWh/kWp/day. The electricity amount possibly stored in the battery is 6.829 kWh.

Weather conditions, such as clouds, rain, or storms, especially at sea where the weather can change rapidly, influence the conversion of solar energy into electrical energy, reducing the efficiency of the PV system. However, this can be anticipated by having an adequate battery supply. The solar panels and battery storage are affected by the available space on the boat, which should not interfere with the boat's operations. In addition, the corrosive marine environment also influences the performance of the PV system. Therefore, engineers must prepare the system to withstand corrosive conditions for a long time, such as by coating the metal components with anti-corrosive paint.

The electricity produced and stored is intended to power electrical devices during the early processing of BSCs, which involves activities like steaming, cold storage, and illumination. The off-grid PV system will help BSC fishermen maintain the quality of their BSCs. The simulation shows that the design of the Off-Grid PV system can provide energy for the steaming and cold storage needs of BSC on-board the boat. The Off-Grid PV system can replace LPG, currently used for steaming BSCs, and operate the freezer, replacing ice-cooled boxes. We base the design of the Off-Grid PV system and the electronic devices for steaming and freezing on components sourced from the industry, so the desired results should at least be close to meeting the requirements of the BSC industry. Overall, the off-grid PV system design simulation has met the requirements for direct installation on the BSC boat. However, during operation, we must create a solid mounting structure for the solar panels and add protective measures to make them corrosion-resistant. It is essential to prioritize fishermen's safety during sea operations and prevent unwanted incidents, such as electrical short circuits.

Technical analysis of the off-grid PV system simulation results using PVsyst 7.2 were compared with Setiyobudi's review results. Table 11 shows the comparison.

Table 11. Comparation PV system.

Analysis data	Simulation of PV system	hybrid/electric propulsion systems
EBT	PV System	PV systems and wind turbines
Software	PVsyst 7.2	Calculation
Type	Off-grid	Hybrid
Energy production	3.540	22.960
Total daily power requirement (Watts)	4.520	17.204
Battery	Total: 8, weight: 356	Total: 240, weight: 3.400

Table 11 shows that hybrid/electric propulsion systems generate significantly more energy as they need to supply a more significant power load. The more substantial number of batteries required compared to the battery needs in the off-grid PV system simulation necessitates ample space and will reduce the mass displacement of the crab fishing vessel. From this comparison, the off-grid PV system simulation design will be more efficiently used by crab fishermen with vessels under 20 GT, as it does not require ample space or heavy load.

3.8 Economic analysis

PVsyst 7.2's financial summary of the off-grid PV system simulation shows that the initial investment is 64,324,237 IDR. Fishermen, enterprises, or other relevant stakeholders solely finance this investment. The system incurs an annual operational cost of 10,973,362.23 IDR, with a levelized cost of electricity (LCOE) amounting to 9,937.84 IDR per kilowatts-hour (kWh). At 68,634.28 IDR, the net present value (NPV) is significantly low, indicating that the 20-year payback period does not fully recover the initial investment. The return on investment (ROI) is significantly low, at 0.1%, suggesting that the investment generates a small return over an extended period. We then use the financial summary to create an annual table that offers a detailed resume of the economic results over 20 years, starting from the initial investment. Tables 12 and 13 present these results.

Table 12. Detail economic result 1.

Year	Running costs	Self-consumption savings
2024	8.301.423	12.819.750
2025	8.537.183	13.178.703
2026	8.779.639	13.537.656
2027	9.028.981	13.896.609
2028	9.285.404	14.255.562
2029	9.549.110	14.614.515
2030	9.820.304	14.973.468
2031	10.099.201	15.332.421
2032	10.386.018	15.691.374
2033	10.680.981	16.050.327
2034	10.984.321	16.409.280
2035	11.296.276	16.768.233
2036	11.617.090	17.127.186
2037	11.947.016	17.486.139
2038	12.286.311	17.845.092
2039	12.635.242	18.204.045
2040	12.994.083	18.562.998
2041	13.363.115	18.921.951
2042	13.742.627	19.280.904
2043	14.132.918	19.639.857
	21.946.724,5	32.459.607,6

Table 12 shows that the off-grid PV system's yearly operational expenses rise because of inflation and escalating maintenance expenditures. Nevertheless, the savings from self-consumption see annual growth because of the improved efficiency of the off-grid PV system. The design simulation results show self-consumption savings of 32,459,607.6 IDR, considerably more significant than the overall operational expenditures of 21,946,724.5 IDR throughout the project's lifespan, and this suggests that the design of the off-grid PV system provides long-term cost savings, even though there is an annual rise in running expenses.

Table 13. Detailed economic result 2.

	Cumulative profit	% amortization
2024	-60.021.068	6.7%
2025	-55.811073	13,2%
2026	-51.700.919	19,6%
2027	-47.696.309	25,9%
2028	-43.802.061	31,9%
2029	-40.022.177	37,8%
2030	-36.359.920	43,5%
2031	-32.817.870	49,0%
2032	-29.397.990	54,3%
2033	-26.101.678	59,4%
2034	-22.929.817	64,4%
2035	-19.882.826	69,1%
2036	-16.960.704	73,6%
2037	-14.163.070	78,0%
2038	-11.489.201	82,1%
2039	-8.938.068	86,1%
2040	-6.508.369	89,9%
2041	-4.198.558	93,5%
2042	-2.006.873	96,9%
2043	68.534	100,1%
	68.534	100,1%

According to Table 13, the cumulative profit will reach a positive value of 68,534 IDR by 2043 and suggests that the off-grid PV system design can generate a profit that covers the total expenditures incurred by 2043, with an amortization value of 100.1%. The result of 100.1% indicates that the initial investment has reached the point where costs are equal to revenues, and future years will generate profits.

The economic analysis for investing in the design of an off-grid PV system will be cost-effective and financially viable throughout the project's duration. Although the investment may require significant time to reach the break-even point, it ultimately proves profitable. Consequently, the off-grid PV system design implemented for the initial crustacean handling on-board can recoup the entire investment and generate profits by the project conclusion. Therefore, it is a viable option for fishermen, businesses, and individuals engaged in the BSC fishing industry to consider constructing BSC fishing boats equipped with off-grid PV systems to manage BSCs on-board.

Economic analysis of the off-grid PV system simulation results using PVsyst 7.2 were compared with Setiyobudi's review results. Table 14 shows the comparison.

Table 14. Comparation PV system.

Analysis data	Simulation of off-grid PV system	hybrid/electric propulsion systems (USD 1 = 16.375,47 IDR per July 29, 2024) (source: ORTAX)
Initial investment	64.324.237 IDR	USD 21.084 = 345.260.409,48 IDR

Hybrid/electric propulsion systems require an initial investment of 345,260,409.48 IDR. This amount is significantly higher than the initial investment needed for the off-grid PV system simulation design, which is only 64,324,237 IDR. In terms of value, the initial investment for the off-grid PV system simulation design is only 18.63% of that required for hybrid/electric propulsion systems. Therefore, for BSC fishermen, who are mostly not large capital holders, investing in the off-grid PV system for steaming and cold storage is more realistic using the simulation design. However, fishermen with significant capital could use the hybrid/electric propulsion system design on BSC fishing vessels.

4 Conclusion

The intensity of GHI throughout the year, which will be converted into electrical energy using a PV system, greatly depends on weather conditions, the angle of the sun, and atmospheric conditions. Based on data from Meteoronorm 8.0, the GHI in the Rembang area reaches 1955.6 kWh/m²/month. This GHI value is auspicious for conversion into electrical energy, making it useful for the initial processing of BSC on-board. The PV system selected is an off-grid type not connected to the grid/PLN, making it easily deployable on boats. Depending on power requirements and cost, you can choose the main components, solar panels, controllers, and batteries. The off-grid PV system used in the marine area must withstand the corrosive environment and ensure safety in case of electrical problems.

The design of the off-grid PV system simulated using PVsyst 7.2 software results in a Normalized Production of 3.54 kWh/kWp/day, which is to be used to meet the electrical energy needs of 4520 Watts/day for the electronic devices used in the initial BSC processing on-board. The initial investment for the off-grid PV system design simulation reaches 64,324,237 IDR. Calculate this investment value using PVsyst 7.2 software based on the minimum energy needs for the initial processing of BSC and the main components of the PV system simulation. The project plan in the simulation is for 20 years, with an OPEX of 10,973,362.23 IDR/year. The values for LCOE, NPV, Payback Period, and ROI are 9,937.84 IDR/kWh, 68,634.28 IDR, 20.0 years, and 0.1%. Respectively, these values indicate that making this simulation into a prototype will be financially profitable by the end of the project.

For future research, we can develop the off-grid PV system design for the initial processing of BSC on-board by utilizing lithium-sulfur or solid-state batteries that offer greater storage capacity and better durability. We can also improve solar panel efficiency by using more efficient and durable solar panels, especially those that can withstand marine environments and perform better in low sunlight conditions, such as at night and in poor weather. Finally, we can create an automated system for the off-grid PV system that can be remotely monitored and controlled for the initial processing of BSC on board.

The next plans include implementing the off-grid PV system on BSC fishing boats in the field. Collaboration with the BSC industry and solar panel technology companies will be sought to refine the off-grid PV system design and operationalize the initial BSC processing. We will also obtain technical and financial support for direct use on BSC fishing boats, resulting in an efficient and sustainable off-grid PV system and initial BSC processing.

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