Performance ratio of the PLTS system for blue swimming crab handling on the boat in field testing and PVsyst software simulation

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Abstract. On the northern coast of Java, some fishermen catch the blue swimming crab (BSC) for more than one day, which risks damaging the BSC; therefore, the fishermen will perform the initial steps of steaming and cold storage on the boat. As an alternative initial process, fishermen can use electrical devices for BSC processing by converting solar energy into electrical energy using a solar power plant (PLTS). We have designed an off-grid PLTS for the initial processing of BSC and lighting. This research aims to determine the performance ratio (PR) of the off-grid PLTS for the initial processing of the BSC compared to simulations using PVsyst software. The method used was qualitative, testing the off-grid PLTS on a boat in Rembang and comparing the PR with the simulation results from the PVsyst software. The off-grid PLTS system exhibited a PR of 0.379, whereas the simulation result was 0.710. The economic analysis indicated that the off-grid PLTS system cost for every kilowatt-hour (kWh) of electricity generated by the PLTS system is IDR 19,497,90. The testing results of the off-grid PLTS system showed low PR, but we hope fishermen can use this system for the initial handling of BSC on the boats.

1. Introduction

Blue Swimming Crabs (BSC) (*Portunus pelagicus*) are a high-value fishery product in the northern coastal areas of Java [1, 2]. The steaming procedure and cold storage on the boat are two post-catch handling procedures that affect the quality of the BSC meat from the catch [3]. Efficient and good steaming equipment and cold storage significantly affect the quality of the BSC meat from "the time" it is caught until it reaches consumers on land. Figure 1 shows the catch of BSC.

BSC fishermen who must operate with traditional boats in the middle of the sea have limitations in terms of stable and environmentally friendly energy sources. Fishermen still use expensive fossil fuels that negatively impact the environment, so we need innovative solutions to address this energy problem [4]. One alternative solution is to apply solar power generation systems (PLTS) as an alternative energy source to support operations on traditional boats [5]. PLTS systems have great potential to provide clean and sustainable energy by harnessing the abundant solar energy in the northern coastal areas of Java [6, 7]. This system can be an effective alternative to meet the energy needs of BSC fishermen.

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Fig. 1. Figure of Blue Swimming Crabs (BSC).

This research aims to calculate and compare the performance ratio (PR) of PLTS systems used for handling crabs on boats through field testing and simulation design of PLTS systems using PVsyst software. PLTS systems can use PVsyst version 7.2 software to design and analyze in detail, resulting in performance data for the designed PLTS system under various conditions and predetermined factors [8, 9]. This research aims to produce an optimal alternative energy solution to maintain the quality of BSC meat and improve the welfare of BSC fishermen in the northern coastal areas of Java.

2. Research method

The study was carried out on BSC fishing vessels weighing over 5 GT in the Tasik Agung region, Rembang, from April 2023 to March 2024. Figure 2 shows the precise position for testing.

Fig. 2. The arrow indicates the placement of the PLTS system testing equipment.

The components utilized in this study comprise an off-grid PLTS system that has been developed, along with electronic equipment for steaming, cold storage, and LED lights.

Table 1. The electrical equipment utilized and its corresponding power consumption needs.

Main component	Total	Power (Watt)	Usage time (Hours)	Peak load (Watt)	Total Daily Power Requirement (Watt)
Electric stove	1	600	2	600	1200
Freezer	1	140	22	140	3080
LED lamp	1	20	12	20	240
				760	4520

This research employed a qualitative methodology, utilizing two treatments: field testing and modeling of the PLTS system using PVsyst software. The PR of the PLTS system was determined by processing the results obtained from field testing and simulation and comparing them. Field testing comprised multiple stages, including an initial survey, system design, installation of the PLTS system, data gathering, and data analysis. The researchers collect data over five consecutive days, starting at 08:00 and ending at 20:00 each day, and they recorded the data at regular intervals of 30 minutes. The PR calculations on the PLTS off-grid system testing data specifically focus on the period between 09:00 and 14:00 UTC+7 when solar energy production is at its highest. The formula for determining the PR of the off-grid PLTS system was as follows.

$$P = V \times I \quad (1)$$

$$P\mathit{input} = Pn \times tn \quad (2)$$

$$Pp = \Sigma Pn \quad (3)$$

$$Ph = \Sigma(Pn \times tn) \quad (4)$$

$$\text{Poutput PLTS} = \text{Poutput PV} \quad (5)$$

$$\eta\text{pv specification} = 21{,}5\% \quad (6)$$

$$\eta pv = \frac{Ppv}{(E \times Ac)} \times 100\% \quad (7)$$

$$\text{PR PLTS } \mathit{Load} = \frac{\mathit{Poutput}\text{ PLTS}}{\mathit{Pinput}} \quad (8)$$

$$\text{PRscc} = \frac{(\mathit{Poutput}\text{ SCC}+\mathit{Pinput}\text{ battery}):2}{\mathit{Pinput}\text{ SCC}} \quad (9)$$

$$\text{PRbattery} = \frac{\mathit{Poutput}\text{ battery}}{(\mathit{Poutput\ SCC}+\ \mathit{Pinput}\text{ battery}):2} \quad (10)$$

$$\text{PRinverter} = \frac{\mathit{Poutput}\text{ inverter}}{\mathit{Pinput}\text{ inverter}} \quad (11)$$

$$\mathit{Losses}\text{ SCC} = \frac{([\mathit{Poutput}\text{ SCC}+\mathit{Pinput\ baterai}]:2 - \mathit{Pinput}\text{ SCC})}{\mathit{Pinput}\text{ SCC}} \times 100\% \quad (12)$$

$$\mathit{Losses}\text{ battery} = \frac{\mathit{Poutput}\text{ battery} - ([\text{Poutput SCC}+\text{Pinput battery}]:2)}{(\text{Poutput SCC}+\text{Pinput battery}):2} \times 100\% \quad (13)$$

$$\mathit{Losses}\text{ inverter} = \frac{(\mathit{Poutput}\text{ inverter} - \mathit{Pinput}\text{ inverter})}{\mathit{Pinput}\text{ inverter}} \times 100\% \quad (14)$$

$$\mathit{Total\ System\ Losses}\text{ l PLTS} = \mathit{Losses}\text{ SCC} + \mathit{Losses}\text{ battery} + \mathit{Losses}\text{ inverter} \quad (15)$$

$$\text{PR system PLTS 1} = 100\% - \mathit{Total\ System\ Losses}\text{ PLTS} \quad (16)$$

$$\text{Psystem 1} = \mathit{Poutput}\text{ trial PLTS x } (\mathit{Poutput}\text{ trial PLTS x PR system 1}) \quad (17)$$

$$\text{PRsystem PLTS 2} = \frac{\mathit{Poutput}\text{ inverter}}{\mathit{Poutput}\text{ pv}} \quad (18)$$

Caution:

Ac	:	Solar panel area	Pp	:	Peak electrical load
Ah	:	Battery capacity	Ppeak	:	Maximum power of solar panel
b	:	Battery	Ppv	:	Maximum power of solar panel
E	:	Solar radiation intensity	PR	:	Performance ratio
I	:	Electric current	pv	:	Solar panel
P	:	Electric power	tn	:	Operational time of electrical device n
Pb	:	Battery power	V	:	Electrical voltage
Ph	:	Total daily electrical load	Vb	:	Battery voltage
Pi	:	Inverter power	Σ	:	Quantity
Pmax	:	Maximum solar panel power	η	:	Efficiency
Pn	:	Power requirement of electrical devices n			

The PVsyst version 7.2 executes a simulation to gain a thorough performance overview of the PLTS system. The simulation stages involve inputting various data, such as geographical coordinates, specifications of electronic equipment, solar panel requirements, controller specifications, inverter specifications, and other simulated components. Subsequently, the process entails formulating the system, conducting a simulation of the formulated design using the provided input data, and scrutinizing the simulation outcomes. The field-testing results are compared with the simulation results of the PLTS system design using PVsyst software, enabling the evaluation of a PR of the PLTS system.

3. Results and discussion

3.1. Off-grid PLTS system device

The test of the PLTS system uses an off-grid configuration. An off-grid PLTS system is a self-sufficient solar power conversion system that functions independently from the grid, producing electrical energy autonomously [10, 11]. The off-grid PLTS system is evaluated on the boat to assess its effectiveness in managing BSCs initially. It comprises essential elements, as illustrated in Table 2. We installed an off-grid PLTS system on a boat weighing over five gross tons (GT). Figure 3 shows the boat used for experimentation with the off-grid PLTS technology.

Table 2. Main component of the off-grid PLTS system.

Main component	Total	Specification
Solar panel	4	120 WP, 12 Volt, and monocrystalline
Solar Charge Controller (SCC) Maximum Power Point Tracking (MPPT)	1	MPPT 100 Ampere and 12 V/24 V/36 V/48 V
Inverter PSW	1	1500 Watt and 12 V
Battery Absorbent Glass Mat (AGM)	4	100 Ah and 12 Volt

Fig. 3. A BSC harvesting boat weighing above five gross tons.

The solar panels are installed on top of the ship with a tilt angle of 30° and an azimuth angle of 0° oriented to the north, based on the ship's operation below the Equator [12]. We mounted the SCC, MCB, and busbar box near the ship's steering for easy monitoring. The inverter is placed below the steering to facilitate supervision. The battery is positioned under the ship's dashboard, close to the box and the inverter. The inverter supplies electricity from the SCC and battery through the electrical terminals to the load. Figure 4 illustrates the arrangement of the essential components of the off-grid PLTS system aboard the boat.

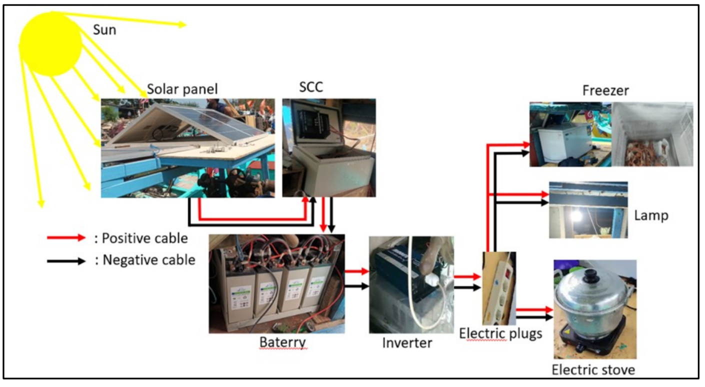

Fig. 4. The position of the component of an off-grid PLTS system on the boat

Initiate data gathering after mounting the off-grid PLTS system on the boat, and we gather data from November 9th to November 13th, 2023. The test data consists of voltage and current measurements obtained from the solar panel input to the SCC, output measurements from the SCC to the battery, output measurements from the battery to the inverter, and the ON/OFF status of electronic equipment. The data recorded these measurements from 08:00 to 20:00 UTC+7 (Table 3-7).

Table 3. Data for day 1.

Time	DC							AC				
	Input Solar Panel to SCC		Output SCC to Battery			Output Battery to Inverter		Output Inverter		On/Off		
	Voltage (volt)	Current (Amp)	Voltage (volt)		Current (Amp)	Voltage (volt)	Current (Amp)	Voltage (volt)	Current (Amp)	Freezer	Electric Stove	LED lamp
08:00:00	13.30	10.25	13.00	12.90	9.44	16.90	14.77	226.00	0.00	On	Off	Off
08:30:00	13.80	13.01	13.60	15.60	12.16	12.80	12.38	228.00	0.80	On	Off	Off
09:00:00	14.10	14.83	13.80	12.50	13.43	12.10	12.32	228.00	0.77	On	Off	Off
09:30:00	14.10	14.59	13.80	12.70	13.51	12.20	14.59	230.00	0.00	On	Off	Off
10:00:00	14.30	15.69	14.10	12.70	11.16	12.20	15.34	229.00	0.00	On	Off	Off
10:30:00	13.30	8.24	13.10	12.50	7.25	11.80	2.33	224.00	0.09	On	Off	Off
11:00:00	13.20	12.09	13.00	12.30	11.67	11.90	7.46	226.00	0.09	On	Off	Off
11:30:00	13.60	16.12	13.40	11.90	16.34	10.90	59.50	220.00	2.64	Off	On	Off
12:00:00	13.80	15.87	13.50	12.00	16.40	10.90	59.50	221.00	2.63	Off	On	Off
12:30:00	13.10	12.90	12.90	11.40	11.83	10.17	59.10	219.00	2.64	Off	On	Off
13:00:00	13.80	12.71	13.50	12.40	12.10	10.90	2.33	229.00	0.00	Off	On	Off
13:30:00	13.40	9.43	13.20	12.10	8.54	10.80	2.32	228.00	0.00	Off	On	Off
14:00:00	13.40	11.79	13.30	12.20	10.92	10.80	2.32	221.00	0.00	Off	On	Off
14:30:00	12.50	10.74	12.80	11.80	9.52	11.60	12.76	226.00	0.79	On	off	Off
15:00:00	12.40	4.66	12.30	12.00	3.70	11.80	12.84	224.00	0.80	On	off	Off
15:30:00	12.40	4.22	12.10	11.80	3.71	11.40	12.59	227.00	0.79	On	off	Off
16:00:00	12.20	2.75	12.00	11.90	1.80	11.80	2.25	230.00	0.00	On	off	Off
16:30:00	11.90	1.27	11.60	11.60	0.50	11.40	12.63	223.00	0.77	On	off	Off
17:00:00	11.80	0.53	11.40	11.50	0.18	11.30	12.06	224.00	0.76	On	Off	Off
17:30:00	9.60	0.36	11.60	11.50	0.42	11.40	3.98	230.00	0.08	On	Off	On
18:00:00	2.90	0.39	11.50	11.50	0.42	11.50	3.85	230.00	0.09	On	Off	On
18:30:00	0.80	0.32	11.60	11.60	0.39	11.50	3.76	225.00	0.09	Off	Off	On
19:00:00	0.09	0.35	11.50	11.60	0.40	11.50	3.37	222.00	0.09	Off	Off	On
19:30:00	0.80	0.35	11.50	11.40	0.39	11.50	3.72	227.00	0.09	Off	Off	On
20:00:00	0.80	0.36	11.50	11.50	0.37	11.50	3.74	223.00	0.09	Off	Off	On

Table 4. Data for day 2.

Time	DC							AC				
	Input Solar Panel to SCC		Output SCC to Battery			Output Battery to Inverter		Output Inverter		On/Off		
	Voltage (volt)	Current (Amp)	Voltage (volt)		Current (Amp)	Voltage (volt)	Current (Amp)	Voltage (volt)	Current (Amp)	Freezer	Electric Stove	LED lamp
08:00:00	13.30	11.32	13.10	12.50	12.40	11.70	2.29	233.00	0.00	On	Off	Off
08:30:00	13.30	13.05	13.10	12.10	12.32	11.30	13.63	232.00	0.81	On	Off	Off
09:00:00	13.30	14.84	13.50	12.20	13.97	11.50	12.73	229.00	0.19	On	Off	Off
09:30:00	14.10	14.59	13.80	12.40	16.56	11.90	2.28	227.00	0.00	On	Off	Off
10:00:00	14.30	17.54	14.00	12.60	16.54	12.00	2.23	230.00	0.00	On	Off	Off
10:30:00	13.40	10.24	13.60	12.30	7.49	11.90	2.18	235.00	0.00	On	Off	Off
11:00:00	12.60	9.98	12.20	11.40	8.94	10.60	58.60	216.00	2.66	off	On	Off
11:30:00	13.20	15.56	13.50	11.90	14.36	11.70	3.30	230.00	0.00	off	On	Off
12:00:00	13.80	12.85	13.60	12.00	12.01	11.80	2.20	232.00	0.00	off	On	Off
12:30:00	13.50	14.88	13.20	12.10	14.07	11.80	3.23	215.00	0.00	off	On	Off
13:00:00	13.50	15.16	13.10	12.30	15.17	11.90	3.28	216.00	0.00	off	On	Off
13:30:00	13.60	12.92	13.40	11.90	11.88	11.80	13.34	225.00	0.77	On	Off	Off
14:00:00	13.30	12.53	13.10	12.00	11.58	11.70	3.35	232.00	0.00	On	Off	Off
14:30:00	12.60	6.51	12.30	11.60	5.30	11.70	15.50	223.00	0.83	On	Off	Off
15:00:00	12.60	9.07	12.40	11.70	3.87	11.60	2.23	230.00	0.00	On	Off	Off
15:30:00	12.20	2.89	12.00	11.70	2.85	11.60	3.31	231.00	0.00	On	Off	Off
16:00:00	12.10	3.17	11.40	11.70	2.04	11.60	2.15	225.00	0.00	On	Off	Off
16:30:00	11.80	1.46	11.60	11.50	0.30	11.50	2.16	221.00	0.00	On	Off	Off
17:00:00	11.70	0.95	11.50	11.30	0.15	11.10	12.87	228.00	0.77	On	Off	Off
17:30:00	11.60	0.51	11.50	11.40	0.51	11.40	4.19	223.00	0.09	On	Off	On
18:00:00	1.80	0.48	11.20	11.20	0.53	11.00	14.17	226.00	0.81	On	Off	On
18:30:00	0.70	0.50	11.10	11.20	0.52	11.00	14.70	225.00	0.81	On	Off	On
19:00:00	0.70	0.48	11.20	11.20	0.53	11.00	14.56	224.00	0.81	On	Off	On
19:30:00	0.80	0.50	11.20	11.20	0.54	10.90	17.53	226.00	0.84	On	Off	On
20:00:00	0.80	0.53	11.10	11.20	0.53	10.90	14.56	225.00	0.46	On	Off	On

Table 5. Data for day 3.

Time	DC							AC				
	Input Solar Panel to SCC		Output SCC to Battery			Output Battery to Inverter		Output Inverter		On/Off		
	Voltage (volt)	Current (Amp)	Voltage (volt)		Current (Amp)	Voltage (volt)	Current (Amp)	Voltage (volt)	Current (Amp)	Freezer	Electric Stove	LED lamp
08:00:00	12.80	11.61	12.60	12.10	10.55	11.00	14.89	226.00	0.86	On	Off	Off
08:30:00	13.20	13.92	12.40	11.80	12.91	11.40	2.10	228.00	0.00	On	Off	Off
09:00:00	13.50	15.73	13.30	12.00	14.71	11.60	2.18	234.00	0.00	On	Off	Off
09:30:00	12.70	10.03	12.40	12.00	17.06	11.10	14.91	228.00	0.84	On	Off	Off
10:00:00	14.30	18.20	14.00	12.30	14.80	11.80	2.11	226.00	0.90	Off	On	Off
10:30:00	12.70	16.61	12.50	11.70	7.17	11.70	2.15	230.00	0.00	On	Off	Off
11:00:00	12.60	6.09	12.40	11.70	15.76	11.70	3.41	228.00	0.00	On	Off	Off
11:30:00	14.70	19.42	14.50	12.00	16.26	11.90	3.42	231.00	0.00	On	Off	Off
12:00:00	14.50	18.71	13.60	12.00	17.41	12.80	14.39	225.00	0.79	On	Off	Off
12:30:00	14.00	16.14	13.70	11.90	14.15	11.90	14.41	226.00	0.81	On	Off	Off
13:00:00	13.70	15.45	13.40	11.90	13.74	11.40	3.15	226.00	0.38	On	Off	Off
13:30:00	13.60	15.23	13.40	11.90	14.60	11.70	2.14	224.00	0.40	On	Off	Off
14:00:00	13.90	13.29	13.60	12.20	10.13	11.70	3.39	226.00	0.00	On	Off	Off
14:30:00	13.60	10.11	13.40	12.10	9.83	11.80	3.67	225.00	0.00	On	Off	Off
15:00:00	13.30	9.99	13.10	12.20	7.12	11.70	3.45	226.00	0.02	On	Off	Off
15:30:00	12.90	7.11	12.70	12.00	6.45	11.80	2.76	226.00	0.00	On	Off	Off
16:00:00	12.80	6.50	12.60	11.90	0.05	11.90	2.55	226.00	0.00	On	Off	Off
16:30:00	11.80	1.35	11.80	11.70	8.42	11.60	14.67	228.00	0.84	On	Off	Off
17:00:00	11.80	0.84	11.60	11.60	8.42	11.50	2.16	229.00	0.00	On	Off	Off
17:30:00	11.70	0.59	11.50	11.50	0.63	11.40	17.05	228.00	0.90	On	Off	On
18:00:00	3.70	0.54	11.50	11.50	0.60	11.40	3.63	229.00	0.09	On	Off	On
18:30:00	0.90	0.54	11.40	11.40	0.39	11.30	13.89	225.00	0.80	On	Off	On
19:00:00	0.80	0.54	11.40	11.40	0.57	11.10	14.40	227.00	0.80	On	Off	On
19:30:00	0.80	0.57	11.40	11.40	0.60	11.40	3.20	221.00	0.09	On	Off	On
20:00:00	0.80	0.56	11.30	11.40	0.61	11.30	3.55	224.00	0.08	On	Off	On

Table 6. Data for day 4.

Time	DC							AC				
	Input Solar Panel to SCC		Output SCC to Battery			Output Battery to Inverter		Output Inverter		On/Off		
	Voltage (volt)	Current (Amp)	Voltage (volt)		Current (Amp)	Voltage (volt)	Current (Amp)	Voltage (volt)	Current (Amp)	Freezer	Electric Stove	LED lamp
08:00:00	13.70	15.31	13.60	12.10	13.81	11.70	3.28	228.00	0.00	Off	Off	Off
08:30:00	13.80	15.45	13.60	12.10	13.61	11.80	3.38	230.00	0.00	Off	Off	Off
09:00:00	14.00	14.43	13.80	12.20	13.94	11.70	3.88	229.00	0.00	Off	Off	Off
09:30:00	14.10	17.83	13.80	12.40	16.45	11.30	3.27	231.00	0.00	Off	Off	Off
10:00:00	14.70	13.59	14.50	12.20	9.71	11.90	3.32	226.00	0.00	Off	Off	Off
10:30:00	13.00	18.15	13.30	11.60	17.91	11.80	16.72	224.00	0.88	On	Off	Off
11:00:00	12.40	6.30	12.10	11.50	4.85	11.20	13.51	226.00	0.84	On	Off	Off
11:30:00	12.30	7.18	12.10	11.60	5.78	11.60	14.11	227.00	0.79	On	Off	Off
12:00:00	12.10	8.67	11.90	11.60	6.71	11.60	3.37	226.00	0.00	On	Off	Off
12:30:00	12.10	7.68	11.90	11.70	6.76	11.60	6.68	225.00	0.00	On	Off	Off
13:00:00	11.30	8.67	11.90	11.60	5.64	11.60	3.31	225.00	0.00	On	Off	Off
13:30:00	12.50	8.67	11.50	11.50	4.64	11.70	6.62	222.00	0.00	On	Off	Off
14:00:00	13.30	13.30	13.90	11.90	14.31	11.80	3.42	223.00	0.00	Off	Off	Off
14:30:00	12.80	7.99	12.70	11.90	9.28	11.60	2.63	226.00	0.00	Off	Off	Off
15:00:00	13.62	9.46	13.10	11.90	9.21	11.80	3.64	228.00	0.00	Off	Off	Off
15:30:00	13.10	9.21	13.40	11.80	9.14	11.90	3.66	229.00	0.00	Off	Off	Off
16:00:00	12.60	0.87	12.40	11.90	5.41	11.90	3.67	228.00	0.00	Off	Off	Off
16:30:00	11.60	0.85	11.50	11.40	0.63	11.50	1.94	222.00	0.00	Off	Off	Off
17:00:00	11.60	0.82	11.40	11.40	0.56	11.40	1.87	221.00	0.00	Off	Off	Off
17:30:00	11.60	0.70	11.50	11.40	0.74	11.40	1.95	223.00	0.77	Off	Off	On
18:00:00	3.30	0.03	11.40	11.40	0.09	11.30	3.49	221.00	0.09	Off	Off	On
18:30:00	0.90	0.01	11.30	11.30	0.07	11.30	4.68	223.00	0.08	Off	Off	On
19:00:00	0.90	0.67	11.30	11.30	0.68	11.20	4.76	223.00	0.09	Off	Off	On
19:30:00	0.80	0.60	11.30	11.30	0.54	11.20	4.29	223.00	0.11	Off	Off	On
20:00:00	0.80	0.61	11.30	11.20	0.57	11.20	4.33	223.00	0.12	Off	Off	On

Table 7. Data for day 5.

Time	DC							AC				
	Input Solar Panel to SCC		Output SCC to Battery			Output Battery to Inverter		Output Inverter		On/Off		
	Voltage (volt)	Current (Amp)	Voltage (volt)		Current (Amp)	Voltage (volt)	Current (Amp)	Voltage (volt)	Current (Amp)	Freezer	Electric Stove	LED lamp
08:00:00	13.20	13.40	12.90	12.10	12.80	11.60	2.02	226.00	0.00	Off	Off	Off
08:30:00	13.20	12.83	13.00	12.20	11.55	12.20	2.22	226.00	0.00	Off	Off	Off
09:00:00	13.10	8.45	12.90	12.00	7.70	11.60	2.39	225.00	0.00	Off	Off	Off
09:30:00	12.50	17.59	12.30	12.00	15.64	11.80	2.62	226.00	0.00	Off	Off	Off
10:00:00	12.60	18.08	12.40	12.10	17.21	11.90	2.72	227.00	0.12	Off	Off	Off
10:30:00	12.80	18.32	12.60	12.10	17.12	11.90	2.39	231.00	0.00	Off	Off	Off
11:00:00	14.30	10.77	14.00	13.00	10.95	11.80	3.35	228.00	0.00	Off	Off	Off
11:30:00	14.20	10.75	13.90	12.90	10.94	11.90	2.92	227.00	0.00	Off	Off	Off
12:00:00	14.50	17.36	14.30	12.80	18.60	11.80	3.42	225.00	0.00	Off	Off	Off
12:30:00	14.40	17.22	14.20	12.70	18.41	11.80	3.43	225.00	0.00	Off	Off	Off
13:00:00	13.00	16.61	12.90	12.70	17.73	11.60	2.79	230.00	0.00	Off	Off	Off
13:30:00	13.10	16.58	12.80	12.80	17.60	11.80	3.02	229.00	0.00	Off	Off	Off
14:00:00	12.70	15.85	12.50	12.20	12.30	11.60	14.27	222.00	0.84	On	Off	Off
14:30:00	12.50	14.61	12.40	12.10	12.65	11.70	14.23	221.00	0.86	On	Off	Off
15:00:00	12.60	4.92	12.30	12.00	10.90	11.70	12.09	223.00	0.78	On	Off	Off
15:30:00	12.00	6.32	11.80	11.50	0.81	11.40	11.84	226.00	0.00	On	Off	Off
16:00:00	11.90	2.19	11.70	11.60	3.55	11.40	11.74	234.00	0.76	On	Off	Off
16:30:00	11.90	2.82	11.70	11.50	1.44	11.40	11.75	224.00	0.00	On	Off	Off
17:00:00	11.70	1.42	11.60	11.50	0.03	11.30	12.39	227.00	0.00	On	Off	Off
17:30:00	7.10	0.01	11.40	11.40	0.11	11.00	4.21	226.00	0.09	On	Off	On
18:00:00	6.60	0.05	11.50	11.40	0.06	11.20	3.61	225.00	0.09	On	Off	On
18:30:00	0.80	0.01	11.50	11.50	0.03	11.40	4.19	223.00	0.09	On	Off	On
19:00:00	0.80	0.64	11.50	11.40	0.65	11.40	3.46	221.00	0.09	Off	Off	On
19:30:00	0.90	0.03	11.40	11.50	0.06	11.40	3.07	223.00	0.00	Off	Off	On
20:00:00	0.80	0.02	11.50	11.50	0.04	11.40	4.10	221.00	0.11	Off	Off	On

Solar energy during daylight hours generates global horizontal irradiation (GHI), the overall quantity of solar radiation received per unit area by a horizontal surface on Earth. GHI is essential for a photovoltaic system [13]. Peak Solar Hours (PSH) significantly influence electricity production, but geographic location, astronomical coordinates, and panel orientation also affect PSH [14]. Observe the PSH during the initial five hours, specifically from 09:00 to 14:00 UTC+7. Hence, data obtained from the off-grid PLTS system testing is exclusively gathered from 09:00 to 14:00 UTC+7 to compute the PR. The data is presented in tables that summarise the power flow from the solar panel to the SCC, from the SCC to the battery, from the battery to the inverter, and from the inverter to the load. The tables are displayed in Tables 8, 9, and 10.

Table 8. Power from solar panel to SCC.

	Global Horizontal Irradiation (W/m^2)	Solar Panel to SCC Voltage (Volt)	Solar Panel to SCC Current (Ampere)	Power (Watt)
	40.95	13.65	13.11	178.95
	53.51	13.51	13.74	185.55
	57.56	13.65	14.99	204.69
	54.66	12.89	11.32	145.87
	49.78	13.38	15.23	203.87
Average	51.29	13.42	13.68	183.79

Table 9. Power from SCC to battery and battery to inverter.

	SCC Out to Battery Voltage (Volt)	SCC Out to Battery Current (Ampere)	Power (Watt)	SCC to Battery In Voltage (Volt)	SCC to Battery in Current (Ampere)	Power (Watt)	Battery to Inverter Voltage (Volt)	Battery to Inverter Current (Ampere)	Power (Watt)
	13.42	12.10	162.42	12.25	12.10	148.23	11.33	21.55	244.20
	13.36	12.96	173.20	12.10	12.96	156.83	11.69	9.70	113.42
	13.35	14.16	189.01	11.96	14.16	169.44	11.75	5.97	70.16
	12.79	9.70	124.07	11.80	9.70	114.46	11.62	7.11	82.61
	13.16	14.93	196.50	12.48	14.93	186.32	11.77	3.94	46.36
Average	13.22	12.77	169.04	12.12	12.77	155.05	11.63	9.65	111.35

Table 10. Power from inverter to load.

	Inverter to Load Voltage (Volt)	Inverter to Load Current (Ampere)	Power (Watt)
	225.00	0.81	181.23
	226.09	0.33	74.40
	227.64	0.37	85.26
	225.82	0.23	51.53
	226.82	0.09	19.80
Average	226.27	0.36	82.44

Several calculation results, such as efficiency, system losses, and the PR of the off-grid PLTS system, can be obtained by applying the formulas mentioned above, along with the data available in Tables 8, 9, and 10. The results of the efficiency, system losses, and PR of the off-grid PLTS system are shown in Table 11.

Table 11. The calculation result of the off-grid PLTS system.

ηpv specification	21.5%
ηpv	67.53%
PR PLTS Load	0.0182
PRscc	0.883
PR battery	0.687
PRinverter	0.740
Losses SCC	-11.83%
Losses battery	-31.29%
Losses inverter	-25.96%
Total System Losses	-69.08%
PRsystem 1	0.309
Psystem 1	56.83 Watt
PRsystem 2	0.449

The off-grid PLTS system has a PR value of 0.309 based on calculations and 0.449 based on measurements.

3.2. Simulation off-grid PLTS system with PVsyst software

Table 12 displays each component and parameter and explains the requirements and parameters for simulating the off-grid system for crab handling aboard the boat.

Table 12. The main component of design simulation is the off-grid PLTS system.

User's Needs	Household	Night ratio 51.4%	Average power 188 Watt	Daily energy 4.52 kWh	-
Component	**Amount**	**Specification**			
Solar panel	4 set	1 String	PV/PLoad 2.5	Average daily energy 1.73 kWh	Nominal power 480 Watt
Controller (Solar Charge Controller [SCC] MPPT and Inverter PSW)	1 set	Universal MPPT and 1000-watt	PV/PConverter 1.15	Nominal power 417 Watt	Thresholds accumulation to SCC
Battery AGM	4 set	4 in Parallel, 12 Volt	Autonomy 0.8 day	Capacity 396 Ah	Store energy 3.80 kWh

The outcomes of the off-grid PLTS system design simulation conducted with PVsyst software are presented in the system performance overview, depicted in Table 13.

PR is determined by dividing the actual energy output of the system by the theoretical energy production when the system is functioning normally [15, 16]. The off-grid PLTS system demonstrates two PR values, 0,309 and 0,449, resulting in an average PR of 0,379. Based on the research findings, the average PR of the off-grid PLTS system testing is 0,379. Additionally, the PR value obtained from simulating the off-grid PLTS system using PVsyst software is 0,710. The obtained comparison ratio for the off-grid PLTS system design simulation is 0.534. Several key factors, including actual weather conditions, cause the difference in PR between field testing and PLTS simulation. Simulations typically use historical or average ideal weather data, while field testing faces real, often changing weather conditions, such as clouds, rain, or high temperatures, which can reduce system performance. Energy losses in the field due to installation quality and system maintenance. In field testing, energy losses that are difficult to model accurately in simulations, such as dust accumulation on panels, inverter inefficiency, and module degradation, occur. Simulations usually do not account for physical degradation or maintenance issues experienced by the system in the field. The accuracy of data input, where simulations use assumptions or estimated data, such as component efficiency and ideal operating conditions. The field's efficiency can vary due to component variations or suboptimal installation.

Table 13. System performance overview.

System Overview	Result
System Kind	Stand Alone Sistem with Batteries
System Production	690 kWh/yr
Specific Production	1436 kWh/kW/yr
Performance Ratio	0.710 (71%)
Normalize Production	3.71 kWh/kWp/day
Array Losses	1.11 kWh/kWp/day
System Losses	0.40 kWh/kWp/day

The research uses an off-grid PLTS system because the BSC fishing boat operating at sea lacks a connection to the land grid. The off-grid PLTS system is fitted with an energy storage battery, guaranteeing continuous availability of electrical energy, even under adverse weather conditions or during the night when solar energy is inaccessible [17, 18]. Design the Off-Grid PLTS system to be portable, facilitating effortless installation on a wide range of seafaring boats [19, 20]. Ensuring a consistent supply of electrical energy is vital for the equipment handling BSCs to function adequately, including operating steaming and chilling machinery.

The off-grid PLTS system, tested on the boat for BSC handling, comprises several vital components. One of the constituents is the solar panel, which transforms solar energy into electrical energy [21, 22]. Monocrystalline solar panels offer high efficiency, cost-effectiveness, and a long lifespan [23, 24]. Under peak solar radiation circumstances, each panel has a maximum energy production capacity of 120 watts, resulting in a total capacity of 480 watts when using four solar panels. The Maximum Power Point Tracking (MPPT) Solar Charge Controller (SCC) optimizes and adjusts the voltage and current generated by the solar panels before transmitting it to the inverter for battery charging purposes [25, 26]. Select the MPPT technology for the SCC to optimize the solar panels' operation at their maximum power point, thus maximizing the efficiency of the energy generated. This energy may then be supplied to the inverter or used to charge the battery [27, 28]. The PSW inverter transforms the Direct Current (DC) generated from the MPPT SCC or the battery into Alternating Current (AC), which is compatible with electronic equipment used for crab handling. The PSW inverter generates a stable and pure sine wave that conforms to household electrical standards, ensuring its compatibility and safety with commonly used electronic equipment.

The SCC MPPT directs the solar panels' electrical energy to the AGM battery for storage. Users can utilize the stored energy during periods of low solar energy, such as at night or during inclement weather. AGM batteries are cost-effective, highly efficient, low-maintenance, and boast a lengthy lifespan. Describe the simulation of the off-grid PLTS design using PVsyst software as follows. The user requires energy for a residential or small-scale setting, with a nighttime energy consumption ratio or total energy consumption at night of 51.4%. Batteries charge throughout the daytime to provide the most energy during the night. The mean power output is 188 watts, and the total daily energy is 4.52 kWh.

The system establishes a series of connections between four solar panels. The PV/PLoad ratio, which represents the proportion of power that the solar panels generate to the electrical load, is 2.5. Solar panels generate 2.5 times the power needed to meet the demand. The solar panels generate an average daily energy output of 1.73 kWh, with each panel having a nominal power of 480 watts. The PVsyst software controller integrates the functionality of two components, namely the MPPT SCC and PSW inverter, into a single set. The simulation demonstrates that the controller power is limited to 1000 watts due to the PVsyst software selection of the optimal specs. The PV/PConverter ratio, which shows how the solar panels' power compares to the controller's transformed power, is 1.15. The controller has a nominal output of 417 watts. The controller determines the thresholds for accumulating self-charging cycles (SCC) based on the battery capacity.

Four AGM batteries are connected in parallel, each with a voltage of 12 volts and a capacity of 100 Ah. The system's autonomy is 0.8 days, indicating that the batteries can provide power to the load for 0.8 days without requiring a recharge from the solar panels. The battery has a total capacity of 396 ampere-hours (Ah) and a stored energy capacity of 3.80 kWh. The PR of the off-grid PLTS system will be assessed by conducting field tests and simulating its performance using PVsyst software. This study derived two distinct PR numbers: the off-grid PLTS system has a mean PR of 0,379. In contrast, the simulated off-grid PLTS system design achieves a PR of 0,710. The comparison between these two PR values is dividing the average PR of the off-grid PLTS system by the PR of the simulated off-grid PLTS system, which yields a value of 0.534. The value of 0.534 signifies that the PR of the off-grid PLTS system is 53.4% compared to that of the simulated off-grid PLTS system design.

3.3. Economic study of an off-grid PLTS system with PVsyst software

Several economic aspects, such as cost components and potential revenue, influence the development of a PLTS system. A thorough consideration of economic value is necessary to ensure that the investment provides the desired return and is profitable in the long run. An off-grid PLTS system for handling Blue Swimming Crabs on boats under 20 GT is designed to be installed and maintained independently by fishermen after receiving proper training. Therefore, the economic value of an off-grid PLTS system will only be calculated using a few key factors. These key factors are:

a. Initial Investment Cost, or the cost incurred to build the off-grid PLTS system.
b. Operational and maintenance costs are for repairing and replacing damaged components.
c. Revenue and Savings: Calculate the energy used for self-consumption to determine whether the off-grid PLTS system will result in savings. d. External Factors, such as inflation due to macroeconomic factors, can affect costs and revenue.
d. Financial Analysis, consisting of [29]:
   - Levelized Cost of Electricity (LCOE), or the average cost of producing one kilowatt-hour (kWh) of electricity over the system's lifetime. This figure includes all costs, including investment, operation, and maintenance.
   - Net Present Value (NPV) or calculating the net value of all expected cash flows, subtracting the initial investment cost.
   - Return on Investment (ROI), or the time needed to recover the initial investment from savings and generated income.
   - Payback Period, or the time required to recover the initial investment from energy cost savings.

To determine the feasibility of using the off-grid PLTS system through simulation using PVsyst software, data on the prices of PLTS system components, installation costs, and economic parameters are needed. The components and costs required for the economic calculation are shown in Table 14.

Table 14. Price table of materials and installation for the off-grid PLTS system.

Item Name	Quantity	Unit	Total (IDR)
Accessories	1	package	IDR 9.513.103
Solar panel 120WP and 12 Volt	4	unit	IDR 3.536.415
Controller	1	package	IDR 2.064.578
Battery AGM 100 Ah and 12 Volt	4	unit	IDR 9.345.000
Box Panel	1	unit	IDR 688.860
Wiring	1	package	IDR 2.689.598
Installation cost	1	package	IDR 7.390.845
Total			**IDR 35.228.400**

In addition to component data and their costs, several elements are required for economic calculations. These include the discount rate, which is the interest rate used to discount future cash flows to their present value; income tax, which is the tax levied by the Government on the income earned by individuals and companies; other income taxes, which includes other taxes related to the PLTS project, such as local taxes or special taxes for the renewable energy industry; dividends, which are profits distributed to shareholders; the depreciation period, which is the time frame over which fixed assets are depreciated based on the estimated economic life of the asset; and the depreciation coefficient, which is the value used to calculate the annual depreciation of fixed assets. Additionally, several components affect the economic calculation, with values shown in Table 15.

By conducting simulations using PVsyst software based on the data in Table 14 and Table 15, the economic calculations for the off-grid PLTS system can yield economic calculation data, as shown in Table 16.

Table 15. Table of economic parameter values for the off-grid PLTS system.

Parameter	Quantity	Description
Maintenance	10%	Per year
Battery replacement	2	Per year
Project lifetime	20	Year
Inflation	2,84%	Per year
Discount rate	1%	Per year
Income tax	1%	Year
Other income tax	1%	Year
Dividends	1%	Year
Depreciation period	1	Year
Depreciation coefficient	1	-
Owner's Equity	IDR 35.228.400	

Table 16. Results of the economic calculations for the off-grid PLTS system.

CAPEX (Installation Costs)	
Total Installation cost	IDR 35.228.400
Total yearly cost	IDR 10.833.135/year
Depreciable Asset	IDR 24.459.097
Financing	
Own Funds	IDR 35.228.400
Subsidies	IDR 0.00
Loans	IDR 0.00
Total Financing	IDR 35.228.400
Expenses	
OPEX (Operating Costs)	IDR 10.833.135/year
Loan Annuities	IDR 0.00/year
Total Expenses	IDR 10.833.135/year
LCOE (Levelized Cost of Electricity)	IDR 19.497,90/kWh
ROI	
NPV	IDR 27.050,76
Payback Period	20.0 year
ROI	0.1%

The LCOE of IDR 19.497,90/kWh indicates that the cost incurred is approximately IDR 19.497,90 for every kWh of electricity generated by the PLTS system. With an NPV of IDR 27.050,76, this project shows potential long-term Profitability. An ROI of 0.1% suggests that the investment in the PLTS system yields minimal profits compared to the total costs incurred. This indicates that the project may need to be sufficiently profitable in the short term. With a payback period of 20 years, it will take about 20 years to recover the initial investment. This relatively long period indicates that the project may provide little return immediately.

4. Conclusion

BSCs, being a valuable seafood commodity, need to ensure that their flesh quality remains excellent from when they are harvested in the water until customers devour them. Steaming and cold storage techniques ensure BSC quality on the boat. Steaming and cold storage aboard the boat uses commonly employed electrical devices, such as electric stoves, freezers, and LED lights, to illuminate the boats. The field testing of the off-grid PLTS system and the simulation design of the off-grid PLTS system using PVsyst software yielded a PR rating of 0.534. The value of 0.534 signifies that the PR of the off-grid PLTS system is 53.4% compared to that of the simulated off-grid PLTS system design. This outcome indicates a substantial disparity between the anticipated effectiveness derived from simulation and the actual performance attained in real-world field settings. Several factors could account for the discrepancy in PR, including the actual weather conditions, energy losses in the field due to installation quality and system maintenance, and the accuracy of data. Field tests and PVsyst software simulations must adequately consider these factors. From the economic analysis of the off-grid PLTS system, Rp for every kWh of electricity generated by the PLTS system. is 19.497.90, NPV is IDR 27.050,76, ROI is 0.1%, and a payback period of 20 years will take about 20 years to recover the initial investment. This relatively long period indicates that the project may provide little return immediately. To anticipate that the study will yield suggestions for utilizing the off-grid PLTS system on BSC fishing vessels to enhance the performance of crab handling and preserve the quality of BSC meat.

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