Technical-economical assessment of solar PV systems on small-scale fishing vessels

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Article Info

ABSTRACT

The source of lighting in ships can be sourced from electrical energy generated by using generators or now can utilize new renewable energy, such as solar energy using PV. Based on the existing potential, Indonesia has good solar energy potential. The measurement results show that the potential for solar energy reaches 6.37 kWh/m^2/day. This potential can certainly be utilized in the marine and fisheries world. The utilization of PV as a source of electrical energy on fishing boats is expected to help support government policies in terms of the blue economy and overcome the limited number of fossil energy sources. In this study, the installation of PV with a size of 100 WP was installed on fishing boats. The need for electrical energy for PV energy output shows that it can meet 50.52% of electrical energy needs. This result is supported by the Wilcoxon test that electrical energy needs can be met by PV with a $p < 0.005$. The results of the economic analysis also show that the use of solar energy as a source of electrical energy provides an IRR of 9%, with a payback period of 8.87 years.

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1. INTRODUCTION

Indonesia is a maritime country, so Indonesia is mostly an ocean rich in marine products [1]–[4]. This statement is supported by the results of the DPR RI plenary session on September 29, 2014 regarding the Maritime Law. This makes the Indonesian nation a step forward in achieving its goals as a Maritime State. In supporting activities as a Maritime State, President Joko Widodo described five pillars as an effort to realize the world's maritime axis. The five pillars are a form of Indonesia's offer of cooperation to the world. First, rebuild the maritime culture. Second, maintaining and managing marine resources with a focus on building seafood sovereignty through the development of the fishing industry, by placing fishermen as the main pillar. Third, develop maritime infrastructure and connectivity by building sea highways, deep seaports, logistics, shipping industry, and maritime tourism. Fourth, develop maritime diplomacy by jointly eliminating sources of maritime conflicts. Fifth, build a maritime defense force [5]. Ships are one of the means of transportation at sea. Ships have advantages in transportation, which can carry more cargo than transportation facilities such as cars or trains. The use of ships as a means of transportation has a relatively less accident rate because in the construction of ships already equipped with facilities for prevention and mitigation [6]–[9].

Along with the growing needs and various types of ships, the need for electric power on board will vary greatly, according to the type of ship (bulk, solid cargo carriers, tankers, containers, cars, crossings, passengers, ships supporting offshore activities, and other) [6], [7]. To meet the electricity demand, two or three generators are used, powered by an emergency generator or a set of emergency batteries. Power plants on ships are generally driven by engines from diesel engines, steam turbines, and gas turbines. So the use of the generator driving engine is as a machine that performs the conversion process of primary energy (fuel) which is converted into mechanical energy driving the generator (rotary power), which is then converted by the generator into electrical energy [6], [10]. On ships, the electric power station or commonly called the auxiliary engine (AE) or diesel engine generator (DEG) which is placed in the engine room, according to the requirements of the ship classification bureau, there must be a minimum of two units or added with emergency power generator (emergency diesel engine generator). Because the electrical installations installed onboard the ship must fully obtain Ship Classification approval starting from the time the new ship is first built on the shipyard.

The power plant onboard, in addition to using a diesel engine, can also utilize energy from sunlight as a source of electrical energy [11], [12]. It can be used as an alternative source of electrical energy because the need for electrical energy will continue to increase every year [11], [13], [14]. This problem almost occurs throughout Indonesia, not apart from the East Nusa Tenggara area. New and renewable energy that fits the topography of the East Nusa Tenggara area is energy from sunlight. East Nusa Tenggara is located around the equator, causing the availability of sunlight throughout the year. Solar energy can be used as a substitute for conventional energy which is starting to be limited and the price is quite expensive [10], [12], [15], [16]. The potential for solar energy in East Nusa Tenggara is 6.37 kWh/m^2, making it possible for East Nusa Tenggara to utilize solar energy as an energy source. Based on data from the Central Statistics Agency of East Nusa Tenggara Province in 2017, the number of boats/ships by type of boat with outboard motor boats amounted to 6,737 units, and the number of boats with motorized boats amounted to 8,871.

Tablolong village is one of the villages whose residents are involved in the marine and fisheries world [17]. So that the use of electricity onboard can be applied in an effort to assist in supplying electrical energy when going to sea. Utilization of solar energy as electrical energy can be done by using solar PV mounted on a ship [11]–[13], [18]. The electrical energy produced can be used to turn on electric equipment and boat lights at night, and be used as fishing aids [10], [15], [19]. The use of solar energy as a source of electrical energy is expected to improve the health (sanitation in the engine room) of the chief engineer and machinists, as well as reduce the use of fossil energy which is not good for the environment [19]–[24]. This new renewable energy utilization can also be combined with a microcontroller system. This system will make it easier for us to know the condition of the PV that we install [25]–[28]. In the use of PV in areas prone to oxidation, it is necessary to pay attention to the equipment so that it is not easily corroded due to weather. This needs to be considered so that PV can be used for a long time [29]–[33].

2. METHOD

The research was conducted from March to November 2021, located in Tablolong village, West Kupang, East Nusa Tenggara. This research was carried out in an applied manner which directly implemented the tools made, then tested the effectiveness of the tools. The research method used is comparative experimental. Experimental comparisons were carried out on ships that were before PV was installed and after PV was installed.

2.1. Experimental PV mini-grid design and construction

The experimental research design uses one fishing boat unit, namely the ship before the PV was installed and the ship after the PV was installed. Data collection in Tablolong village, West Kupang, East Nusa Tenggara. The experiment was carried out for 22 days. The results of PV utilization, design, and construction can be seen in the image. PV specifications and their installation on the ship can be seen in Table 1 and Figure 1.

Figure 1. PV mini-grid design for fishing boats

Table 1. The spesification of solar power plant on fishing boat

Electrical Characteristics	Spesification
PV Panel 100 WP	
Type of cell	Monocrystalline silicon
Module Efficiency	16.31%
Maximum Power (Wp)	100 W
Maximum Power Voltage	19 V
Maximum Power Current	5.26 A
Open Circuit Voltage	23 V
Short Circuit Current	5.53 A
Temperature Range	-40 ºC to +85 ºC
BCU	
Load Current	10 A
End of Charge Voltage	13.9 V (27.8 V)
Boost Charge Voltage	14.4 V (28.8 V)
System Voltage	12 V
Self-Consumption	< 4 mA
Ambient Temperature	-25 ºC to +50 ºC
Battery	
Nominal Voltage	12 V
Nominal Capacity	100 V
Inverter	
Input Voltage	12 V
Input Voltage Range	DC 10 – 14.8 V
Output Voltage	AC 220 – 240 V
Continous Power	500 W
Output Frequency	50 ± 3 Hz/60 ± 3 Hz
Efficiency up to	90.5 %
Lamp	
Voltage	DC 12 V
Working Life	50000 H
Beam Angle	120º
Color Temperature	6500 – 7000 K

2.2. Validity test

The valid instrument means a measuring instrument that can be used to obtain data (measure) what should be measured. The results of the research are valid if there is a similarity between the data collected and the actual data that occurs in the object under study. In this study used instruments. Avometer to measure current and voltage. Thermo-hygrometer for measuring ambient temperature and humidity levels. A questionnaire to measure attitudes whose answers range from very positive to very negative.

After the results of the collected questionnaire answers were tabulated, then the validity test was carried out with factor analysis, namely by correlating the number of factor scores with the total score. To calculate it, the person product moment formula is used. In the research the validity results show valid results. Validity testing here is done using the SPSS program.

2.3. Reliability test

A reliable instrument is an instrument used several times to measure the same object that will produce the same data results. Reliable research results, if there are similarities in data at different times. To test the reliability of the instrument in this study, the alpha cronbach correlation coefficient was used. If r alpha is positive and greater than r table then the variable is reliable. General guidelines for determining the reliability of questions if the cronbach's alpha value is above 0.4044. The higher the alpha coefficient, the higher the consistency of the measured reliability. Reliability testing using SPSS program.

2.4. Associative test

The associative test is used to find and find out the relationship between the variables in the research. In this study, the relationship was carried out using a comparative test. The comparative test carried out is a comparative test of two paired groups, because it comes from two different data groups, namely, respondents before and after using PV. The test used is the Wilcoxon test (nonparametric test). The results of the analysis of the comparative test will be obtained p value. The next value is used to test the hypothesis and draw conclusions about the relationship between variables or to state that there is no relationship between variables. If the p value <0.05, then there is a significant difference between the two groups of data. Associative testing is done by using the SPSS program.

2.5. Calculation of power and energy production of PV mini-grid

Measurements to determine the amount of voltage and electric current produced by PV are carried out every hour from 06.00 to 18.00, by adding weather conditions, ambient temperature, and air at the time of measurement. In conducting the analysis in this study, several calculations were used, such as the power and electrical energy produced by PV and the percentage of electrical energy needed on fishing boats. The results of the electrical power produced by PV are obtained from the calculation results between the voltage (Vdc) and current (Idc) of the measurement results in the PV (Formula 1). The results of electrical energy produced by PV are obtained from the results of calculations by finding the area under the graph (Figure 2). The equation for calculating electrical energy based on the area under the graph can be seen in Formula 2. The results of the electrical energy produced by PV are then used to calculate the proportion of PV electrical energy to the electrical energy needs of fishing boats by using the Formula 3.

$$P = Vdc \; x \; Idc \tag{1}$$

$$A = \int_b^a y \, dx \tag{2}$$

$$The \; Proportion \; of \; Electrical \; Energy \; Needs \; (\%) = \frac{PV \; Energy \; Generated}{Electrical \; Energy \; Needs} \tag{3}$$
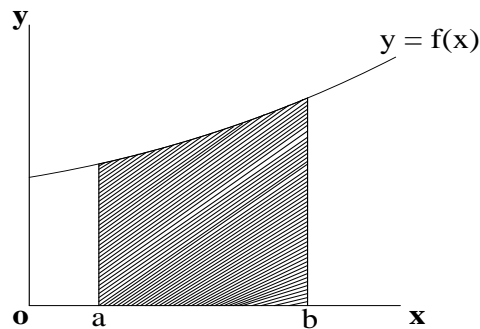

Figure 2. PV mini-grid output power

2.6. Observation and measurement of environmental conditions

The environmental conditions in this study consisted of weather conditions, ambient temperature, and air humidity levels. The results of these observations and measurements are based on the provisions of the BMKG (meteorology, climatology, and geophysics agency) namely Instructions MET/101/SYNOP/2000. Weather conditions were carried out by observation, which was divided into three categories, namely sunny, cloudy, and rainy. To distinguish sunny, cloudy, and rainy weather in an area based on the number of clouds in the area.

2.7. Economic impact of PV installation

The economic analysis of a PV project carried out is an indicator of project profitability and project recovery. To determine the profitability of installing PV systems on campus, we use the methods of payback period, net present value (NPV), and internal rate of return. The calculation of the simple payback period (SPBP), NPV, and IRR method can be seen in the calculation below [34]. The discount rate (r) usually in Indonesia can be 4.25% and based on the provisions of the regulation of the minister of energy and mineral resources No. 17 of 2013, regarding the purchase of electricity by state electricity company from photovoltaic solar power plants, amounting to US$25 cents/kWh.

$$SPBP = Investment \; or \; capital \; cost/ \; saving \; cost \; per \; year \tag{4}$$

$$NPV = Income \; cash \; flow – Outcome \; cash \; flow \tag{5}$$

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_o \tag{6}$$

3. RESULTS AND DISCUSSION

3.1. Electrical energy from PV mini-grid

The utilization of PV on fishing boats in Tablolong village gives the result that the electrical energy produced from PV is an average of 593.83 Wh. The electrical energy produced is influenced by the weather, such as solar radiation, wind speed, temperature and humidity. Data on the results of using PV on fishing boats can be seen in the Table 2. The results of the output of electrical energy from PV per day can be seen in the Figure 3.

Table 2. PV mini-grid measurement results in the field

Day	Radiation (kW/m^2/day)	Wind Speed (m/s)	Temperature (ºC)	Humidity (%)	Energy (Wh)
1	6.53	5.02	27.21	78.56	620.35
2	6.3	4.99	27.07	82.31	579.6
3	6.11	4.55	27.3	81	568.23
4	6.31	4.35	27.56	79.94	593.14
5	6.51	4.98	27.69	79.56	611.94
6	4.43	6.55	27.17	79.44	420.85
7	5.96	7.97	27.56	69.19	572.16
8	6.44	7.84	27.62	67.88	592.48
9	5.69	7.34	27.73	73.56	529.17
10	5.78	6.73	27.52	77.56	520.2
11	6.65	5.2	27.55	76	591.85
12	6.66	4.62	27.48	77.94	599.4
13	6.67	4.52	27.39	79.31	586.96
14	6.63	4.97	27.42	80.69	596.7
15	6.42	4.47	27.55	80.19	609.9
16	6.68	5.01	27.57	80.44	641.28
17	6.77	5.57	27.47	78.12	656.69
18	6.82	5.71	27.48	75.62	641.08
19	6.73	6.06	27.28	79.12	619.16
20	6.74	5.7	27.53	74.56	626.82
21	6.73	5.8	27.47	76.94	632.62
22	6.67	5.41	27.62	76.5	653.66
Average	6.37	5.61	27.47	77.47	593.83
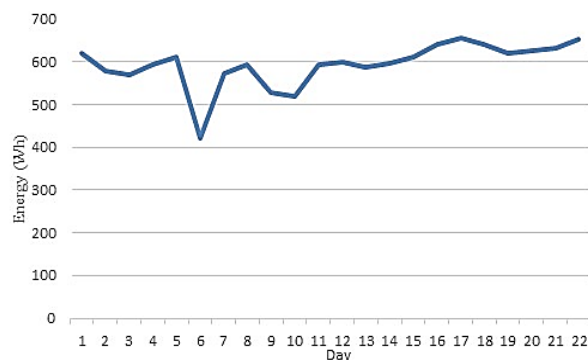
Figure 3. Energy output of PV

The measurement results show the potential for solar energy of 6.37 kW/m^2, wind speed 5.61 m/s, air temperature 27.47ºC, humidity 77.47%. With such environmental conditions, it can produce electrical energy of 593.83 Wh per day. The largest energy output occurred on day 17, amounting to 656.69 Wh. The output of electrical energy which is so varied is influenced by environmental conditions around the research area. From the data obtained, it is found that the electricity obtained from PV can meet the electrical energy needs of fishermen. The percentage of electrical energy needed for energy produced by solar power plants gives a value of 50.52%. This value indicates that strengthening the electrical energy produced from PV can meet the needs of electrical energy when fishing at night. This need includes 3 lamps for 5 W lighting and 10 W communication tools.

Based on the indicators that have been carried out before and before the activity, the results show that there is an increase in the use of PV electrical energy on fishing boats. This increase is seen from the availability of electrical energy to support fish activities on fishing boats. The results of the questionnaire were tested using the Wilcoxon test in Table 3.

Table 3. Wilcoxon test results in electrical energy before and after using PV

	n	Median (minimum-maksimum)	p
Electrical energy needs before using PV	24	3 (2-6)	0.001
Electrical energy needs after using PV	24	5 (3-5)	

Wilcoxon test results show a comparison of the electrical energy requirements of the ship before training and before installation. There were 3 people with lower electrical energy needs after installation before installation, 5 permanent people, and 16 people having a statement that the electrical energy needs on the ship were met. The statistical results in Table 3 showing the results of the Wilcoxon test, obtained a significant value of 0.001 (p<0.05), thus there is a significant difference between before training and before training.

From the data obtained, it is obtained that the electricity obtained from PVcan meet the electrical energy needs of the fishermen with a value of 5. The percentage of electrical energy needs for energy produced by PV gives a value of 50.52%. This value shows that strengthening the electrical energy generated from PV can meet the needs of electrical energy when fishing at night. This need includes 3 lamps for 5 W lighting and 10 W communication tools.

3.2. Economic impact of PV installation

The use of solar energy as a source of electrical energy on fishing boats in Tablolong village is also calculated for its economic impact. The economy referred to here is about the economics of using PV as electrical energy as long as the impact is utilized. The economic calculation of PV here is seen from the calculation of the payback period (PP), net present value (NPV), and the internal rate of return (IRR). Determination of operational and maintenance costs/ year is determined at 10% of the initial investment. The interest rate is determined at 4.25% based on the interest rate of Bank Indonesia. The results of these calculations can be seen in the Table 4.

The results of the economic analysis of the use of PV values on fishing boats obtained an IRR of 9% and this is possible to do. The results of the analysis also show that the payback period value shows that this utilization yields a yield of 8.87 years, with an NPV of IDR 4,449,662.50. This will certainly be one of the solutions in saving financing and helping fishermen in utilizing renewable energy where this potential is very abundant in Indonesia, especially in East Nusa Tenggara.

Table 4. Energy cost calculation and feasibility solar power plant investment

Cost and Feasibility	Description
Investment Cost	IDR 7,000,000
Operational and Maintenance Costs/year	IDR 70,000
Saving-1/year	IDR 789,564.86
i	4.25 %
n	25 Years
SPBP	8.87 Years
Net Present Value (NPV)	IDR 4,449,662.50
IRR	9%

4.   CONCLUSION

The utilization of solar energy as a source of electrical energy on fishing vessels with a size of 100 WP can meet the needs of the electrical load. This utilization can supply 50.52% of the electrical energy needs on board. This result is supported by the results of the Wilcoxon test which shows a significant difference in the need for electrical energy with PV with p<0.005. The results of the economic analysis also show that the use of solar energy as a source of electrical energy provides an IRR of 9%, with a payback period of 8.87 years. This shows that economically the use of solar power plants on fishing vessels is of good economic value.

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