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Design and Implementation of Solar Cells as an Alternative Power Source for Pinisi Ships

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Abstract. *The Pinisi is a traditional Indonesian ship recognized as a maritime cultural masterpiece and remains widely utilized, particularly in liveaboard tourism. The increasing demand for sustainable and innovative energy solutions in the tourism and maritime industries highlights the relevance of adopting solar cells as an alternative energy source for lighting on these ships. Solar cells, primarily made from silicon, efficiently convert solar radiation into electrical energy. This study evaluates the feasibility of using solar cells to power lighting systems on Pinisi ships operating in the Selayar Islands. Solar radiation data from NASA Surface Meteorology was utilized to estimate the optimal power output of solar modules. The analysis indicates that 10 solar cell modules can generate an energy output of 19.480 kWh, sufficient to meet the ship's lighting requirements. Configurations were optimized for different decks, ensuring efficient energy distribution while maintaining sustainability. The findings demonstrate that implementing solar cells on Pinisi ships not only fulfills their energy needs but also supports the maritime tourism industry by providing an eco-friendly and innovative energy solution. This approach contributes to the preservation of maritime heritage while addressing contemporary environmental challenges.*

Keywords: Pinisi ship, solar cells, energy conversion, maritime tourism innovation

Introduction

The use of renewable energy has become a critical focus in sectors like maritime transport and tourism due to increasing awareness of the environmental harms caused by fossil fuel consumption [1]–[3]. In this context, the Pinisi ship, a significant maritime cultural heritage from South Sulawesi, Indonesia [4], presents a unique opportunity for integration with modern technologies such as solar cells. Incorporating solar technology into the Pinisi not only enhances its energy efficiency and reduces its carbon footprint but also aligns with sustainable tourism goals by minimizing environmental impacts and promoting eco-friendly practices. This approach not only helps preserve Indonesia's rich nautical heritage but also exemplifies how traditional vessels can adapt to contemporary environmental challenges.

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A key issue faced by tourist vessels like the Pinisi is the high energy demand for operations, particularly for lighting, which is typically met by diesel-powered generators [5], [6]. These generators are not only expensive and environmentally harmful [7], but their use also undermines the image of the Pinisi as a symbol of tourism that emphasizes natural beauty and cultural heritage [8], [9].This vessel is designed by drawing inspiration from similar ships found in Labuan Bajo, which have become a major attraction for tourists in that region. By adopting a similar concept, the aim is to enhance public interest and tourism in Selayar Island [10]. Therefore, replacing conventional energy sources with solar cells presents a highly attractive alternative, especially considering Indonesia's abundant solar radiation throughout the year.

The literature review indicates that the application of solar cell technology on various types of ships has seen significant development in recent years. Several studies, such as the design of adding solar panels to passenger ships, have shown promising results, including a reduction in fuel consumption for generators [11]. Additionally, other research has been conducted on tugboats, demonstrating the capability to reduce dependence on diesel oil by using solar panels as an alternative energy source for lighting [12]. Other studies have demonstrated that solar cells can effectively reduce dependence on fossil fuels and minimize carbon dioxide emissions. However, research on the application of solar cells to traditional ships like the Pinisi remains limited. This creates a research opportunity to further explore how this technology can be adapted and applied to Pinisi ships operating in specific regions, such as the Selayar Islands. The primary objective of this study is to evaluate the potential use of solar cells as an alternative energy source on Pinisi ships, particularly to meet the electrical lighting needs. The study hypothesizes that solar cells can effectively replace diesel generators while maintaining or even improving the operational efficiency of the vessel [6], [13]. By utilizing solar radiation data from NASA Surface Meteorology, this research aims to calculate the optimal power output that can be generated by various configurations of solar cells on the Pinisi ship [14].

This research focuses exclusively on analyzing the application of solar cells for meeting the lighting electricity needs on the Pinisi ship, deliberately excluding other aspects such as propulsion systems or the operation of additional onboard equipment. The study's methodology encompasses several critical steps: first, collecting comprehensive data on solar radiation specific to the operating environment of the ship [14]; second, calculating the power output generated by the installed solar cells under various conditions; and third, evaluating the energy efficiency of different configurations of solar cell installations. By isolating these parameters, the research aims to provide a detailed understanding of how solar technology can be effectively integrated into the lighting systems of Pinisi ships. This focused approach will yield valuable insights into the potential benefits and challenges associated with using solar cells in maritime contexts. The anticipated results are expected to highlight the feasibility of enhancing energy efficiency through renewable sources, thus promoting innovation in the development of more sustainable maritime tourism practices. By contributing to the body of knowledge on renewable energy applications in traditional maritime vessels, this study seeks to support the broader goal of reducing the environmental impact of tourism and fostering advancements in eco-friendly maritime technologies.

Theoretical Background

The conversion of energy from sunlight offers a highly practical solution to the ongoing energy crisis, particularly in light of increasing regulations aimed at limiting the use of fossil fuels, which are among the largest contributors to air pollution. These regulations have created opportunities

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for the adoption of environmentally friendly energy sources, such as solar panels. This is especially relevant in a country like Indonesia, where abundant sunlight is available year-round, providing a reliable resource for renewable energy generation. Solar cells, which convert sunlight into electricity, represent a renewable energy alternative that can be used to power various ship systems, including lighting, as exemplified by their potential application on Pinisi tourist ship.

The integration of solar energy in the maritime sector has been globally explored, with studies underscoring its significant potential to reduce reliance on fossil fuels, lower greenhouse gas emissions [15], and enhance the sustainability of maritime operations. Specifically, for Pinisi ship, which are emblematic of Indonesia's rich maritime heritage and often used for tourism, the use of solar panels not only aligns with environmental conservation efforts but also supports the long-term operational efficiency of these vessels. By utilizing solar energy, Pinisi ship can benefit from reduced fuel costs and emissions, thus contributing to the broader agenda of sustainable maritime development.

This renewable energy solution holds particular promise in maritime regions where energy demands are high, and traditional fuel sources are both costly and environmentally damaging. The successful application of solar power on vessels like the Pinisi could set a benchmark for the adoption of similar technologies in other sectors of the maritime industry, reinforcing the global transition towards cleaner and more sustainable energy practices.

Materials and Methods

Solar Module Configuration

In this study, three solar cell module configurations are utilized to meet the lighting requirements of a 300 GT Ro-Ro ship. The PVSK-675M module, a high-efficiency monocrystalline panel, is employed for the main deck lighting due to its ability to provide stable power output, even in low light conditions. The SP355P6-72 module, a polycrystalline panel with 72 cells, is applied to the navigation deck, offering an optimal balance between efficiency and cost to meet lower power demands. The ST72P335 module, also a 72-cell polycrystalline panel, is used for the double deck lighting, which requires less power but demands stable performance and durability in maritime environments. A key consideration in this study is determining which of these modules is most suitable for shipboard use, given the spatial constraints typical of maritime vessels. The implementation of these various types of modules reflects how the selection of the right solar cell technology can be tailored to the specific needs of each area of the ship, so that power optimization is achieved and the maximum potential of solar energy can be utilized.

Main Dimensions of the Pinisi

The type of vessel and its principal dimensions are used as a reference to facilitate the design process and the installation of solar cell modules. This data was obtained from previous research on the design of a Pinisi-type tourist ship for the Selayar Islands region [10]. Meanwhile, the study related to solar energy potential and the determination of the solar cell size refers to formulas and calculations from previous research, which examined the potential of solar energy as a renewable alternative to reduce dependence on diesel engines, known for their high fuel consumption and environmental pollution [15]. The data for the Pinisi ship used in this study can be found in **Table**

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1. To facilitate understanding and provide more insights about this vessel, the design of the Pinisi tourist ship can be seen in **Figure 1**.

Table 1. Main data of pinisi-type tourist vessel [10]

Main Dimensions	Unit
Length over all (*LOA*)	26 meters
Leght Pore Perpendicular (*LPP*)	24 meters
Breadth (*B*)	6.10 meters
Depth (*D*)	2.48 meters
Draft (*T*)	1.60 meters

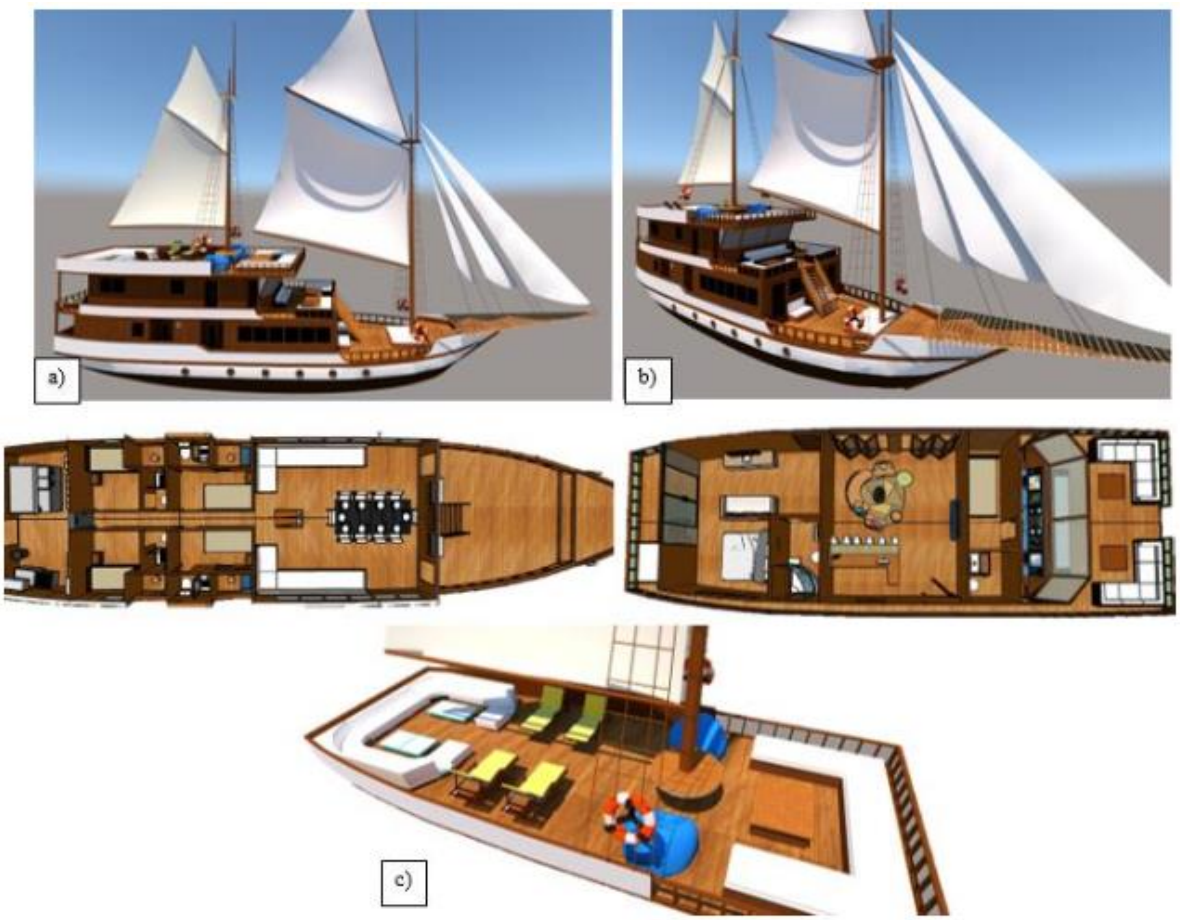

Figure 1. 3D view of pinisi tourist ship, a) side view, b) front view, c) deck view

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Calculation of Solar Cell Capacity

The power generated by a solar cell is the result of the multiplication of current and voltage across the solar cell. The product of the current and voltage values generates the maximum power (P_{max}) at a specific voltage (V_{max}). The current flowing through the external circuit when the solar cell generates maximum power is known as the maximum current (I_{max}). The formula can be written as follows:

$$P_{max} = V_{max} \times I_{max} \quad (1)$$

Where:

P_{max} = Maximum output power from the solar panel (W_p)

V_{max} = Maximum output voltage from the solar panel (V)

I_{max} = Maximum output current from the solar panel (A)

The ratio between the product of current and voltage at maximum power and the product of $I_{sc} \times V_{oc}$ is called the fill factor (*FF*) and can be formulated as follows:

$$FF = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}} \quad (2)$$

Where:

FF = Fill factor

V_{oc} = Open-circuit voltage of the solar panel when Isc is zero (V)

I_{sc} = Short-circuit current of the solar panel when Voc is zero (A)

The power generated by a solar cell is influenced by conversion efficiency and sunlight intensity. The conversion efficiency is defined as follows:

$$n = \frac{I_{sc} \times V_{oc} \times FF}{\phi \times A} \quad (3)$$

Where:

n = Conversion efficiency of the solar cell

ϕ = Solar insolation (W/m^2)

A = Area of the solar panel (m^2).

Results and Discussion

The data required for measuring electrical energy potential includes solar radiation for a specific region, in this case, the Selayar Islands. Solar radiation data can be obtained from online sources, such as the NASA Surface Meteorology and Solar Energy [16]. Below is a table showing the solar radiation data for the Selayar Islands throughout the year 2023. The solar radiation data for the entire year of 2023 can be found in **Table 2**.

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Table 2. Solar radiation data entire year of 2023

Month	Power (07.00 – 17.00)*
January	4.14 kW
February	4.65 kW
March	5.23 kW
April	5.25 kW
May	5.22 kW
June	5.12 kW
July	4.95 kW
August	5.63 kW
September	5.75 kW
October	6.05 kW
November	5.22 kW
December	4.20 kW

*The time period for collecting solar heat data is selected from 07.00 Am to 05.00 Pm

The potential electrical energy from solar radiation has been outlined in the table above. Subsequently, this energy will be absorbed by the solar cells, allowing the potential energy to be utilized. The application of solar cell technology, which includes solar modules and supporting equipment, will be discussed in detail. In standard testing conditions, the catalog specifies a radiation level of 1000 W/m² and a module temperature of 25°C. This efficiency value indicates the amount of power that can be generated by the solar cells from the received solar radiation. Thus, it will be possible to determine the actual power output under field conditions based on the solar radiation available. The conversion efficiency values for the solar panels can be found in **Table 3**.

Table 3. The variation in solar module efficiency from different catalogs on the market

Modul	V_{oc} (V)	I_{sc} (A)	*FF*	P_{max} (W_p)	*A* (m^2)	Insolation (kWh/m^2)	Efficient (n)
CS6W-555MS [17]	49.8	14.05	0.79	555	2.563	1000	0.216
ST72P340 [18]	45.00	9.41	0.80	340	1.931	1000	0.180
SP290P6-60 [19]	38.95	9.63	0.77	290	1.637	1000	0.177

After obtaining the efficiency values of the solar modules, the next step is to calculate the potential electrical energy from the solar modules based on the solar energy potential. The potential of the solar modules is determined by three factors: solar radiation, area, and module efficiency. The following **Table 4** provides a summary of the potential for each type of module.

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Table 4. Electrical potential of different solar module variations

Product	Model	Energy Min (kWh)	Energy Max (kWh)	Average Energy (kWh)
Hiku6	CS6W-555MS	2.292	3.349	2.833
Jskye	ST72P340	1.438	2.102	1.778
SpolarPV	SP290P6-60	1.200	1.754	1.484

In this system, the battery generates a DC electrical flow measured in ampere-hours (Ah). Therefore, the electrical energy produced by the solar cells is also converted into electrical units with the same measurement, ampere-hours. Based on the general electrical equation $P = I\ V$ and with a charger voltage of 48 V to accommodate the solar energy over 10 hours, the required capacity can be calculated. The results are provided in **Table 5**.

$$Ah = \frac{\sum e}{V} \times 1000 \tag{4}$$

Where:

Ah = Battery Capacity (Ah)

$\sum e$ = Average energy current (kWh)

V = Battery charging voltage (V).

Table 5. Amperage capacity per module unit

Product	Model	Energy Min (kWh)	Energi Max (kWh)	Average Energy (kWh)	Ampere – hours (Ah)
Hiku6	CS6W-555MS	2.292	3.349	2.833	59.027
Jskye	ST72P340	1.438	2.102	1.778	37.041
SpolarPV	SP290P6-60	1.200	1.754	1.484	30.916

An inverter converts the DC electrical flow produced by the battery into AC electrical flow [20]. With an efficiency of 90%, if the incoming DC power is 100 watts, the resulting AC power would be 90 watts. If the variable to be determined is the amount of AC power produced and the efficiency is 85%, then the AC power output of the inverter can be calculated as follows, and the results can be seen in **Table 6**.

$$E_{out} = 85\% \times E_{min} \tag{5}$$

Where:

Eout = Output Energy (kWh)

Emin = Minimal Energy (kWh)

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Table 6. Power output capacity per module unit

Product	Model	Total Energy (kWh)	Total Power (kW)	Power Output (kW)
Hiku6	CS6W-555MS	2.292	0.229	0.194
Jskye	ST72P340	1.438	0.143	0.122
SpolarPV	SP290P6-60	1.200	0.120	0.102

Based on the calculations, the effectiveness of the three types of solar modules can be evaluated. The CS6W-555MS module was selected because it produces the highest output power among the options, thus providing optimal support for the lighting needs of the Pinisi ship. Additionally, with dimensions of 2.26 × 1.13 meters, it helps minimize the number of modules required.

Pinisi Electrical Power Requirements

Table 7. The power requirements for navigation deck lighting under two sailing conditions

Day Sail	Power (kW)	Total Sail (8 Hours)	Energy Required (kWh)
Captain Room	0.030	8	0.240
Toilet Captain	0.015	8	0.120
Toilet VIP Room	0.021	8	0.168
Mini Bar	0.015	8	0.120
VIP Room	0.084	8	0.672
	Total		1.320

Night Sail	Power (kW)	Total Sail (4 Hours)	Energy Required (kWh)
Navigation Room	0.063	4	0.252
Captain Room	0.030	4	0.120
Toilet Captain	0.015	4	0.060
Day Room	0.105	4	0.420
Mini Bar	0.015	4	0.060
VIP Room	0.084	4	0.336
Toilet VIP Room	0.021	4	0.084
Bow Open Deck	0.105	4	0.420
Aft Open Deck	0.042	4	0.168
Open Deck (PS/SB)	0.063	4	0.252
Accommod. Alleys & Stairs	0.063	4	0.252
	Total		2.424

The lighting on the ship requires an electrical power source. This study covers the electricity consumption for lighting devices on the Pinisi ship, including navigation deck lighting (JL – 1), main deck lighting (JL – 2), double deck lighting (JL – 3), and emergency lighting. Each lighting device consists of a fixture with light bulbs. The research evaluates the electrical power needs for

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lighting on a Pinisi ship during daytime and nighttime conditions while operating in the Selayar Islands. The results can be seen in **Table 7**, **Table 8**, and **Table 9**.

Table 8. The power requirements for main deck lighting under two sailing conditions

Day Sail	Power (kW)	Total Sail (8 Hours)	Energy Required (kWh)
Mess Room	0.330	8	2.640
Single Room 1	0.030	8	0.240
Single Room 2	0.030	8	0.240
Single Room 3	0.022	8	0.176
Single Room 4	0.022	8	0.176
Galley	0.204	8	1.632
Cutting Table & Stove	0.034	8	0.272
Toilet	0.060	8	0.480
VIP Room 1	0.015	8	0.120
VIP Room 2	0.015	8	0.120
VIP Room 3	0.015	8	0.120
VIP Room 4	0.015	8	0.120
	Total		6.336

Night Sail	Power (kW)	Total Sail (4 Hours)	Energy Required (kWh)
Bow Open Deck	0.136	4	0.544
Aft Open Deck	0.136	4	0.544
Mess Room	0.033	4	0.132
Single room 1 & 2	0.060	4	0.240
Single Room 3 & 4	0.044	4	0.176
Galley	0.204	4	0.816
Kitchen	0.034	4	0.136
Toilet Single Room	0.060	4	0.240
VIP Room 1 & 2	0.030	4	0.120
VIP Room 3 & 4	0.030	4	0.120
Accommodation & Stairs	0.045	4	0.180
	Total		3.248

Application of Solar Cells on Pinisi Ships

The requirements for solar modules to provide lighting are calculated based on the sample electrical load requirements of the ship and the available space for the installation of these modules. In this case, four variations are considered to meet the lighting power needs of the Pinisi ship. In **Table 10**, the total power requirement for main deck lighting is 3.890 kWh, which means that only 5 solar modules are needed for a single 12-hour voyage.

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Table 9. The power requirements for doble bottom lighting under two sailing conditions

Day Sail	Power (kW)	Total Sail (8 Hours)	Energy Required (kWh)
Engine Room	0.084	8	0.672
Engine control room	0.034	8	0.272
Twin room 1 & 2	0.084	8	0.672
Crew room 1 &2	0.044	8	0.352
Toilet twin room 1 & 2	0.030	8	0.240
Toilet crew	0.015	8	0.120
Accommodation & Stairs	0.030	8	0.240
	Total		2.568

Night Sail	Power (kW)	Total Sail (4 Hours)	Energy Required (kWh)
Engine Room	0.084	4	0.336
Engine control room	0.034	4	0.136
Twin room 1 & 2	0.084	4	0.336
Crew room 1 & 2	0.440	4	0.176
Toilet twin Room 1 & 2	0.030	4	0.120
Toilet crew	0.015	4	0.060
Accommodation & Stairs	0.030	4	0.120
Void Room	0.015	4	0.060
	Total		1.344

Table 10. Lighting variations, 1 lighting, 2 lighting and 3 lighting

Navigation deck lighting	Energy (kWh)	Main deck Lighting	Energy (kWh)	Double Bottom Lighting	Energy (kWh)
Day sail	1.320	Day sail	6.336	Day sail	2.568
Night Sail	2.424	Night Sail	3.248	Night Sail	1.344
Total	3.744	Total	9.584	Total	3.912
Electricity Supply 2 Solar Modules (2 × 1.948)	3.890	Electricity Supply 5 Solar Modules (5 × 1.948)	9.740	Electricity Supply 2 Solar Modules (2 × 1.948)	3.890

Conclusions

The potential for harnessing solar energy with solar cells on the Pinisi ship in the Selayar Archipelago is 2.292 kWh per module. The total electrical energy required for lighting the Pinisi ship during a single 12-hour voyage amounts to 17.702 kWh. The study assessed the application of solar cell technology for different lighting needs on the ship. For navigation deck lighting, which requires 3.744 kWh, two solar modules are utilized, generating an output of 3.890 kWh. Main deck lighting, with a demand of 9.584 kWh, is supported by five solar modules, providing an output

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of 9.740 kWh. For double deck lighting, which needs 3.912 kWh, two solar modules produce an output of 3.890 kWh. These results demonstrate that the solar modules are effective in meeting the ship's lighting requirements, optimizing energy use, and enhancing the overall sustainability of the Pinisi ship.

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