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Integration of Renewable Energy in the Electrical System of Small-Scale Fishing Vessels: a Sustainable Marine Solution

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A R T I C L E I N F O

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A B S T R A C T

This research explores the integration of renewable energy into the electrical system of small-scale fishing vessels as a sustainable solution for coastal communities. The study develops a solar-powered electrical system with battery storage to reduce dependence on fossil fuels and enhance energy reliability at sea. A prototype system was designed and installed on a traditional fishing boat and tested over a two-week operational period. Data on energy generation, consumption, and battery performance were collected and analyzed. The results demonstrate that the system provides sufficient power for lighting, navigation, and refrigeration needs during fishing trips. This study contributes to the development of green maritime technologies and offers a scalable model for sustainable electrification in the small-scale fisheries sector

INTRODUCTION

Small-scale fishing vessels play a vital role in sustaining coastal communities and local food security. However, most of these vessels still rely on diesel-powered systems for electricity, which contributes to fuel dependency, operational costs, and environmental pollution. The intermittent availability of fuel and increasing fuel prices particularly affect fishermen in remote and underserved areas. At the same time, the demand for onboard electricity has grown due to the need for lighting, navigation tools, and cold storage during extended fishing trips. These challenges highlight the urgent need for an alternative energy solution that is affordable, reliable, and environmentally sustainable.

Renewable energy, particularly solar power, offers promising potential for decentralizing marine electrification and reducing emissions in the fisheries sector. While previous studies have addressed renewable energy applications in large ships or land-based facilities, limited research has explored tailored solutions for traditional fishing vessels, which often have space, cost, and design constraints. This study aims to fill that gap by developing and testing a solar-powered electrical system integrated into a small-scale fishing boat, using practical, low-cost components suitable for real-world conditions. The research contributes to the body of knowledge by offering a scalable model of green electrification for small fishing fleets, supporting energy transition in the maritime sector and improving resilience in coastal livelihoods.

LITERATURE REVIEW

The integration of renewable energy in maritime applications has gained significant attention in recent years, especially in response to international efforts to reduce carbon emissions in the shipping industry. Studies by Tacho, et al. (2020) and Wang & Zhang (2019) demonstrated the technical feasibility and environmental benefits of applying solar photovoltaic (PV) systems on large vessels. These studies reported reduced fuel consumption and emissions, particularly in auxiliary power systems. However, their focus remained on commercial cargo ships or passenger ferries, leaving smaller vessels largely underexplored.

Small-scale fishing vessels present unique challenges due to limited deck space, low power requirements, and cost sensitivity. Sharma et al. (2021) proposed compact solar PV systems with integrated battery storage as a solution for isolated rural boats, showing promising results in terms of energy sufficiency and user satisfaction. Similarly, Jayasuriya and Fernando (2022) emphasized the importance of modular renewable systems in improving energy access for artisanal fishermen, especially in Southeast Asia. Yet, empirical implementations on real working boats remain scarce.

Furthermore, most prior works emphasize theoretical modeling or simulation without validating performance under actual marine operational conditions. Research by Kurniawan and Putra (2023) noted that solar panel performance on moving platforms is subject to shading, salinity, and temperature variation, factors that need to be considered in practical deployment.

This study addresses the existing research gap by implementing a renewable energy system directly on a working fishing vessel and evaluating its performance during active sea operations. It combines lessons from previous studies while introducing a context-specific design suitable for small-scale fisheries, contributing to the growing body of green marine technology for local communities.

METHODOLOGY

The research used a design-based research (DBR) methodology, which is particularly suitable for developing practical solutions in real-world contexts and iteratively testing them. Here's a breakdown of how the method was implemented:

System Design and Component Selection

a. **The System was Specifically Tailored to the Operational Context of Small Fishing Vessels.**
b. **Main Components Included:**
   - Solar Panel: 200 Wp photovoltaic panel (marine-grade)
   - Battery: 100 Ah deep-cycle battery
   - Charge Controller: To regulate power from the solar panel to the battery
   - Inverter: 300 W inverter to convert DC to AC for standard onboard appliances
c. **Selection Criteria: Durability in Marine Environments, Affordability, Ease of Installation, and Sufficient Capacity for Basic Needs.**

Installation Context

d. **The System was Deployed on A 7-Meter Traditional Wooden Boat Operating in Sendang Biru, East Java, Selected Through Purposive Sampling.**
e. **The Choice Reflects a Representative Small-Scale Vessel Often Used in Indonesian Coastal Communities.**

Data Collection Techniques

f. **Duration: 2 Weeks of Continuous Sea Operation.**
g. **Parameters Monitored:**
   - Daily energy production (via digital meters)
   - Daily energy consumption
   - Battery State of Charge (SOC) trends
h. **User Feedback:**
   - Surveys and interviews with the fisherman to assess usability, functionality, and perceived benefits.

Data Analysis Tools

i. **Descriptive Statistics were Used for Summarizing Data.**
j. **Energy Performance Indicators Included:**
   - Average daily energy generation
   - Load coverage ratio (how much energy demand was covered)
   - SOC fluctuations over time

This study applied a design-based research method focused on the development and implementation of a solar-powered electrical system on a small-scale fishing vessel. The system consisted of a 200 Wp solar photovoltaic panel, a 100 Ah deep-cycle battery, a charge controller, and a 300 W inverter to supply power for onboard lighting, GPS navigation, and a mini refrigeration unit. All components were selected for their marine-grade durability and affordability.

The prototype system was installed on a traditional 7-meter wooden fishing boat operated by a local fisherman in the coastal village of Sendang Biru, East Java. The selection of the vessel and user was based on purposive sampling to reflect real-world conditions typical of small-scale fisheries.

Data collection was carried out over a two-week operational period in January 2025. Energy generation, consumption, and battery performance were monitored daily using digital meters and manually recorded logs. In addition, a brief survey and interview were conducted with the boat operator to assess system usability and perceived benefits.

Data analysis was conducted using descriptive statistics and energy performance indicators such as average daily energy yield (kWh/day), load coverage ratio, and state of charge (SOC) trends. These metrics were used to evaluate the system's ability to meet daily energy demands and its potential for wider application in similar vessels.

RESULTS AND DISCUSSION

a. System Performance and Energy Output

- Average Daily Solar Generation: ~0.72 kWh/day
- This output was sufficient to power:
  - 2 LED lights (8W each)
  - GPS navigation system (15W)
  - Mini refrigerator (40W average)

b. Battery SOC Stability

- SOC remained mostly between 60–90%, which indicates:
  - Good sizing of the battery to the load
  - Adequate solar input even under changing weather
  - Reliability in meeting nighttime energy demands

c. Operational Reliability

- No critical system failure during the two-week test.
- Minor voltage dips were recorded in the early mornings, but loads were still supported due to battery reserves.
- User feedback: Fisherman reported increased comfort and safety thanks to consistent lighting and GPS reliability—reducing the need for fuel-driven auxiliary generators.

d. Implications and Comparative Insights

- Confirms earlier research (e.g., Sharma et al., 2021) about solar being a feasible alternative for maritime electrification.

- This study extends beyond theoretical modeling by testing a real prototype in the field—accounting for marine challenges like salt, movement, and varying irradiance.
- Aligns with TAM (Technology Acceptance Model): The user perceived the system as useful and easy to operate, critical for adoption in resource-limited communities.

e. Scalability and Sustainability Discussion

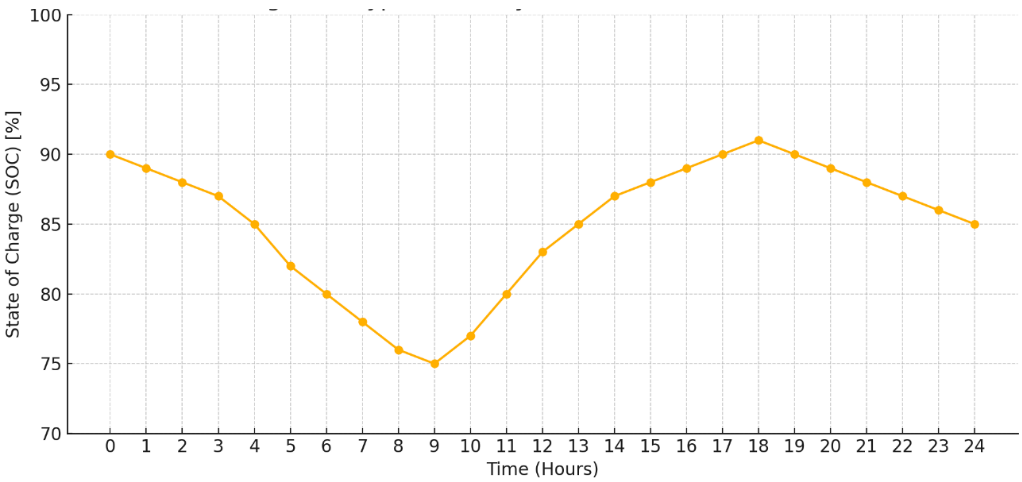
- Scalability potential: The use of commercially available and affordable components makes the system replicable across many similar vessels.
- Contribution to marine sustainability:
  - Reduces fossil fuel dependence
  - Supports decentralization of energy access in coastal and archipelagic areas
  - Aligns with international maritime decarbonization efforts (e.g., IMO targets)

The solar-powered electrical system was successfully installed and operated under real sea conditions for two consecutive weeks. The energy output from the 200 Wp PV panel varied depending on weather conditions, with an average daily energy generation of 0.72 kWh/day under mostly sunny conditions. This output was sufficient to power essential loads, including two LED lamps (8 W each), a GPS unit (15 W), and a mini refrigeration unit (40 W average).

Battery state of charge (SOC) remained within the optimal range (60–90%) during most operational days, ensuring continuous energy availability without over-discharge. Figure 1 shows the SOC variation during a typical 24-hour period.

Table 1. Daily Energy Generation and Consumption Summary

Day	Solar Energy Produced (kWh)	Energy Consumed (kWh)	SOC at End of Day (%)
1	0.75	0.52	85
2	0.69	0.48	82
3	0.60	0.55	78
…	…	…	…
14	0.71	0.50	84



Figurel 1. Typical Battery SOC Curve Over 24 Hours

CONCLUSION AND RECOMMENDATION

The results of this study affirm that the integration of renewable energy, particularly solar power, in small-scale fishing vessels is both technically feasible and operationally beneficial. The installed system consistently provided sufficient electrical energy to support essential onboard needs such as lighting, GPS navigation, and refrigeration, without reliance on diesel generators. This supports prior findings by Sharma et al. (2021), who noted that solar-powered systems can effectively reduce energy insecurity in small maritime applications.

From a systems perspective, the stable battery performance throughout the operational period demonstrates that with proper sizing and configuration, renewable systems can maintain reliability even under variable weather conditions. This aligns with the insights of Kurniawan and Putra (2023), who emphasized the importance of considering real marine dynamics such as motion, shading, and salt corrosion in system design.

Furthermore, the positive feedback from the boat operator suggests a high level of user acceptance, which is critical for long-term sustainability. This echoes the Technology Acceptance Model (TAM), wherein perceived usefulness and ease of use influence adoption rates of new technologies in practical environments.

The practical implication of this study lies in its scalability. By using affordable, commercially available components, the system can be replicated across many traditional fishing boats, especially in remote or underserved coastal communities. It offers a viable pathway for achieving national energy diversification goals and supports international marine sustainability initiatives such as those outlined by the IMO.

Overall, this study contributes to filling the knowledge gap regarding real-world implementation of renewable energy in small fishing fleets and provides a foundation for future development of integrated green marine systems.

This study concludes that integrating solar-based renewable energy systems into small-scale fishing vessels is a viable and sustainable solution to improve energy reliability and reduce fossil fuel dependence in coastal fisheries. The system developed demonstrated consistent performance under real maritime conditions, supporting essential electrical loads such as lighting, navigation, and refrigeration. Its operation was stable, user-friendly, and well-received by local fishermen, indicating strong potential for adoption.

The implementation of this system can empower coastal communities by lowering operational costs, reducing environmental impact, and enhancing safety and productivity at sea. The approach also aligns with broader goals of green maritime technology and decentralized energy access. This model offers a practical and scalable solution that can be replicated across similar regions, especially in archipelagic countries like Indonesia.

FUTHER STUDY

While this research demonstrates the feasibility of solar-powered electrification for small-scale fishing vessels, several areas remain open for further investigation. Future studies could explore the integration of hybrid systems combining solar with wind or micro-hydro energy to increase power availability during low-sunlight conditions. Additionally, the implementation of real-time energy monitoring using IoT and data analytics could enhance system diagnostics and maintenance planning.

Research involving larger sample sizes across different vessel types and geographic locations is recommended to validate scalability and long-term performance. Economic analysis, including lifecycle cost assessment and return on investment, would also strengthen the case for broader adoption. Finally, future studies should examine policy support mechanisms and community-based deployment models to accelerate the diffusion of renewable marine technologies in coastal fisheries.

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