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Optimization of renewable energy-based electrical systems on tourist ships in Labuan Bajo

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ABSTRACT

The use of fossil fuels on tourist boats in Labuan Bajo poses challenges in the form of high operational costs and significant environmental impacts. This study aims to optimize the renewable energy-based electrical system by utilizing a hybrid photovoltaic and generator system on tourist boats. The methods used include simulation and technical, economic, and socio-cultural analysis to evaluate the feasibility and efficiency of the system. The results of the study show that technically, the hybrid photovoltaic (PV)-generator system is able to improve energy efficiency and reliability of electricity supply, especially in dealing with fluctuations in power needs. From an economic aspect, this system has been proven to reduce fossil fuel consumption by up to 40%, which has an impact on long-term operational cost savings, even though the initial investment is quite high. Socio-culturally, the implementation of this system supports sustainability values and provides a positive image for the tourism industry in Labuan Bajo as an environmentally friendly destination. The use of a hybrid PV-generator system is an innovative and sustainable solution for tourist boats in Labuan Bajo, which not only improves technical efficiency and economic benefits but also supports environmental conservation and sustainability-based tourism.

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1. INTRODUCTION

Labuan Bajo, as a super priority tourism destination in Indonesia, is experiencing a surge in electricity demand along with the growth of the tourism sector [1]-[6]. The government and national electricity company have shown their commitment to the transition to new and renewable energy by building solar power plants on the surrounding islands, such as Papagarang Island, Messah, and Seraya Maranu. These solar power plants make a significant contribution in providing environmentally friendly electricity that not only supports community operations, but also encourages the growth of small businesses such as fish storage and ice production [7]-[12].

The commitment to clean energy is also reflected in the increase in the new and renewable energy mix in Flores, which has reached more than 15%. The potential of resources such as solar, geothermal, and hydro power is the foundation of the electricity system in this region [13]-[15]. For example, the Ulumbu Geothermal Power Plant has succeeded in supplying internationally certified, environmentally friendly electricity, supporting Indonesia's target of net-zero emissions by 2060. However, the main challenge still lies in the low application of new and renewable energy technology on tourist boats that are an integral part of

tourism in Labuan Bajo. The majority of ships still use fossil fuels, which have a negative impact on the environment and are not in line with the vision of sustainability [16]-[19].

This study aims to develop a new and renewable energy-based electrical system on tourist ships to reduce carbon emissions and increase energy efficiency [20]-[26]. By integrating solar energy-based technology or a hybrid system, it is expected to support tourism sustainability and increase the attractiveness of Labuan Bajo as an environmentally friendly destination. In addition, this optimization also provides economic benefits by reducing operational costs and creating a more sustainable tourism experience for tourists [27]-[32].

The methods used in this study include technical and economic analysis to evaluate the efficiency of the fossil fuel-based tourist ship electrical system compared to the new and renewable energy-based system. The study also involves collecting field data and interviews with ship operators to identify implementation challenges and develop an optimal electrical system prototype. The results of this study are expected to provide innovative solutions while supporting the energy transition agenda in Indonesia and the sustainability of tourism in Labuan Bajo.

2. METHOD

This study uses a combination of quantitative and qualitative approaches to optimize the renewable energy-based electrical system on a tourist ship in Labuan Bajo. The research method begins with collecting primary data through a field survey involving measuring energy consumption on the tourist ship, collecting technical data on the current electrical system, and assessing the potential for renewable energy such as solar power. This data is complemented by in-depth interviews with ship operators, technicians, and related parties to identify implementation challenges and understand the need for a more efficient and environmentally friendly electrical system.

Furthermore, a technical analysis is carried out to evaluate the efficiency of the current fossil-fueled ship electrical system compared to the potential for integrating renewable energy, especially solar panel technology or a hybrid system. System modeling and simulation are used to predict performance and energy efficiency under various operational conditions. An economic analysis is also carried out to evaluate financial feasibility, including calculating investment costs, operational savings, and potential return on investment (ROI).

This study also includes the development of a prototype of a renewable energy-based electrical system, which is then tested on a small scale on one of the tourist ships. This prototype will be evaluated based on technical performance, sustainability, and user perception. The results of all these analyses and tests are expected to provide strategic recommendations in integrating renewable energy systems on tourist ships, supporting the national energy transition, and improving the sustainability of the tourism sector in Labuan Bajo.

In this study, the methods used include several approaches with an integrated approach. This study is expected to produce practical recommendations for optimizing renewable energy-based electrical systems on tourist ships, from technical, economic, and environmental aspects. A clearer explanation of the approach is as follows:

- Quantitative and qualitative approach: This study will collect technical data on energy consumption, efficiency of ship electrical systems, and renewable energy potential in the Labuan Bajo area for quantitative data. This quantitative data involves direct measurements, such as fuel consumption, electrical system power capacity, and solar or hybrid power potential on tourist ships. Qualitative data is collected through in-depth interviews with ship operators, port authorities, and related parties in the energy and tourism sectors. This interview aims to understand the challenges of implementing renewable energy systems on tourist ships and stakeholder perceptions of energy sustainability.
- Technical analysis: Technical analysis is conducted to evaluate the performance of the fossil-fueled ship's electrical system compared to the potential application of renewable energy-based technology, such as solar panels or hybrid systems. This analysis involves system simulations and energy efficiency calculations to determine the optimal design.
- Economic analysis: This approach is used to evaluate the financial feasibility of integrating renewable energy on tourist ships. The parameters analyzed include initial investment costs, operating costs, potential fuel savings, and ROI.
- Modeling and simulation: This research include the development of a prototype of a renewable energy-based electrical system that can be applied to tourist ships. This prototype will be tested to assess technical performance, sustainability, and user acceptance. To estimate the efficiency of the system under various operating conditions, modeling methods are used to simulate the performance of renewable energy technologies, such as solar power conversion or hybrid systems, in meeting the power needs of tourist ships.

3. RESULTS AND DISCUSSION

The electrical system on the tourist phinisi ship in Labuan Bajo is designed to support the operational needs of the ship and the comfort of passengers. Generally, this ship uses a generator-based electrical system as the main source of electricity, with a capacity that is adjusted to meet needs such as lighting, air conditioning, kitchen equipment, water pumps, and navigation devices. Generators usually use diesel fuel, which is economical and reliable for marine use. On ships, generators with a size of 5500 VA are usually used. The generators used are 2 units. The use of this generator is appropriate because the average electrical load requirement on a phinisi ship is 4976 W. This electrical load can be seen clearly in Table 1. In addition, tourist phinisi ships also often use inverters to convert DC power from batteries into AC power that is compatible with modern electronic equipment. With this combination of traditional and modern technology, phinisi ships can provide a comfortable tourist experience while maintaining energy efficiency.

The electrical distribution system on the ship includes a distribution panel that regulates the distribution of power to various devices and areas of the ship. This panel is equipped with a circuit breaker to protect the system from disturbances such as short circuits or overloads. To ensure safety, the electrical system is designed to be waterproof and resistant to corrosion due to exposure to seawater.

Table 1. Electrical load on tourist boats in Labuan Bajo

Equipment	Specification	Energy (Wh/day)	Position
Outdoor lighting	7 W/220 VAC/LED	1344	Deck
	30 W/220 VAC/LED	720	Mast
	10 W/220 VAC/LED	240	Deck
Room lighting	7 W/220 VAC/LED	168	Bridge
	7 W/220 VAC/LED	504	Cabin
	7 W/220 VAC/LED	336	Engine room
Automatic water pump	125 W/ 220 VAC	6000	Engine room
AC	1PK/ 220 VAC	63360	Cabin
Audio	45 W/ 220 VAC	180	Bridge
Rice cooker	1450 W/ 220 VAC	5800	Kitchen
Mixer	200 W/ 220 VAC	1000	Kitchen
Refrigerator	94 W/ 220 VAC	2256	Kitchen
Rig radio	25 W/ 220 VAC	100	Bridge
AIS	10 W/ 220 VAC	40	Bridge

3.1. Hybrid electrical system on a tourist ship

The use of a hybrid photovoltaic (PV) and generator system with the AC coupling method on ships is an innovative solution to meet energy needs efficiently. This system integrates solar panels as a renewable energy source with a fossil fuel generator as a backup, allowing ships to reduce fuel consumption and carbon emissions. In the AC coupling configuration, the PV inverter converts the electrical energy generated by the solar panels into alternating current (AC) that is compatible with the ship's electrical network. This energy is then combined with power from the generator through a centralized electricity distribution system. The main advantage of this method is its flexibility, because the generator can function as a backup when solar energy production is insufficient, such as at night or during bad weather. In addition, this system can be equipped with batteries to store surplus energy from PV, thereby increasing the efficiency and reliability of the system. By implementing a hybrid PV-generator AC coupling, ships can reduce their dependence on fossil fuels, save operational costs, and contribute to environmental conservation. In addition to generators, some modern ships can also be equipped with solar power systems as an additional energy source. Solar panels are installed on the roof of the ship to charge the battery during the day. This system helps reduce the fuel consumption of generators, especially for low-power needs such as LED lighting and small electronic devices.

In this system, the need for electrical loads on the ship can be met. This is because there is a division of load fulfillment from the use of PV and generators. The system works with several events, including when the load is the same as PV production, the load is greater than PV production, the load is smaller than PV production, and there is no energy production from PV, as shown in Figure 1. The condition of the load being the same as PV production will result in all energy production produced by the PV serving the load, and the generator operating at 20%-30% of the installed capacity. The condition of the load being greater than PV production will result in all energy production from the PV serving the load, and the lack of energy from the load being served by the generator. The condition of the load being smaller than PV production will result in some energy production from the PV serving the load, and the generator operating at 20%-30% of the installed capacity. The condition of no energy production from PV will occur either because it is night or the weather conditions are very bad, then the entire load will be served by the generator.

Figure 2 illustrates the operating scenario of the hybrid PV-generator solution with a maximum penetration of 70% of the installed capacity of the generator at 100%, 75%, and 50% load in sunny weather, less sunny weather, and at night. Savings with this scenario can reach 60%. The 100% load scenario of the generator capacity is very rare. However, with this assumption, the generator operation follows the power supply from the PV. The generator works at a minimum of 20%-30% of capacity. When the PV power supply is greater than 70% of the generator capacity, the PV will automatically reduce the power supply so that the generator works at a minimum of 20%-30% of capacity. When the PV power supply is greater than the load, the PV will automatically reduce the power supply so that the generator works at a minimum of 20%-30% of capacity. In the system created, the use of the hybrid system is more focused on energy needs in lighting and communication systems. The use of electrical energy from PV systems on ships is often focused on the power needs for lights and communication devices. Solar panels generate electricity that can be used directly or stored in batteries to support the operation of these devices. Ship lights, such as navigation lights, cabin lights, and emergency lights, require relatively little power but are very important for the safety and operation of the ship. Likewise, communication devices such as radios, electronic navigation systems, and satellite devices require a stable power supply to maintain connectivity and safety during the voyage.

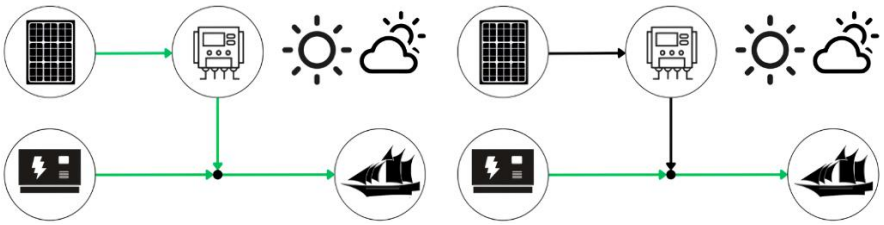

Figure 1. Hybrid system with AC coupling

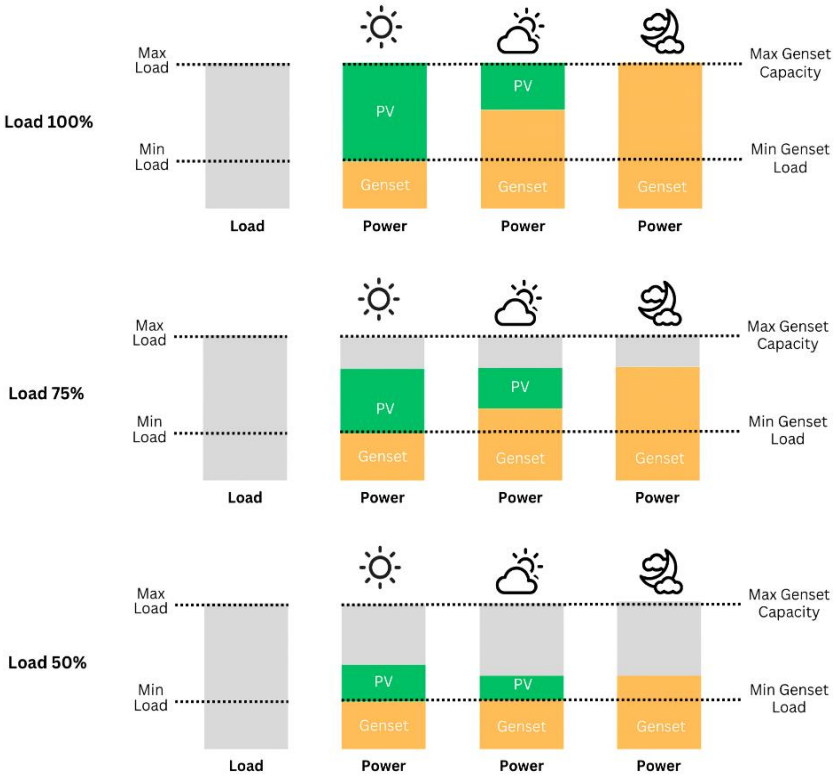

Figure 2. Parallel operation scenario of hybrid PV-genset

By utilizing PV systems for these needs, ships can reduce the load on the main generator, thereby saving fuel and extending the life of the generator. In addition, the use of solar energy provides sustainability

advantages because it does not produce greenhouse gas emissions. By storing energy using batteries, this system can still provide power at night or when the weather is cloudy. This approach is not only energy efficient but also supports the sustainability of ship operations by minimizing carbon footprints and operational costs.

The use of PV on ships has various advantages that make it a sustainable energy solution. One of the advantages is that PV, as an environmentally friendly renewable energy source, does not produce carbon emissions, thus helping to reduce the environmental impact of ship operations. In addition, PV systems can reduce fossil fuel consumption, generate operational cost savings, and extend the life of the main generator by reducing its workload. PV also operates without producing noise, improving comfort on board, and is suitable for small power needs such as navigation lights, communication devices, and other electronic equipment. In terms of maintenance, solar panels are relatively easy to maintain because they do not have many moving parts that are prone to damage. However, PV systems also have disadvantages that need to be considered. PV performance is highly dependent on weather conditions, so production is reduced during cloudy weather or at night. Ships often have limited space for installing solar panels, limiting the amount of energy that can be generated. The initial cost of the installation, including panels, inverters, and storage batteries, is quite high compared to conventional systems. In addition, PV's energy conversion efficiency is still limited, making it less ideal for meeting large power needs such as main engines or ship propulsion systems. Corrosive marine environments can also affect the durability of solar panels, requiring additional maintenance to protect components from damage due to exposure to salt and moisture. Thus, while PV offers sustainability and efficiency benefits for small loads, its integration with other power sources is often necessary to meet the full energy needs of a ship.

3.2. Economics of hybrid electrical systems on tourist ships

The results of the study on the optimization of renewable energy-based electrical systems on tourist boats in Labuan Bajo show significant potential in reducing fossil fuel consumption and carbon emissions. Technical analysis revealed that the use of solar panels for primary power needs, combined with lithium batteries as energy storage, can provide up to 60-80% of the ship's electricity needs in normal weather conditions. The designed hybrid system also shows higher efficiency compared to fossil fuel-based electrical systems, especially in the operation of electronic equipment and lighting. From an economic aspect, this system has been proven to reduce fossil fuel consumption by up to 40%, which has an impact on long-term operational cost savings, even though the initial investment is quite high.

Prototype testing showed stable technical performance, with battery life reaching 8-10 hours of operation without additional supply. Simulations showed that this system can be fully integrated on small to medium-sized tourist boats, without sacrificing space for passengers or goods. In addition, economic analysis indicated that the initial investment in the renewable energy system can be returned in 3-5 years through fuel savings, with a potential ROI of 25-30% per year.

In terms of sustainability, the implementation of this system supports the national energy transition agenda and strengthens Labuan Bajo's image as an environmentally friendly destination. Based on interviews with boat operators, the majority welcomed the integration of this technology because it provides operational efficiency and attracts environmentally conscious tourists. However, the study also noted challenges such as relatively high initial investment costs and the need for technical training for boat operators. Solutions in the form of government subsidies or tax incentives could be a strategic step to support the widespread adoption of this technology. These results emphasize the importance of collaboration between the government, industry players, and local communities to accelerate the implementation of renewable energy, making Labuan Bajo a model for sustainable tourism in Indonesia.

3.3. Public views on the use of hybrid systems on tourist ships in Labuan Bajo

Conducting in-depth interviews with ship operators, port authorities, and stakeholders in the energy and tourism sectors in Labuan Bajo can provide in-depth insights into the implementation of hybrid PV and generator systems on tourist ships. These results show considerable enthusiasm for the implementation of hybrid PV and generators on Labuan Bajo tourist ships. Although challenges such as initial costs and infrastructure limitations still exist, the expected benefits, such as reduced emissions, fuel savings, and improved tourist experience, are significant. Collaboration between ship operators, port authorities, energy, and tourism sectors is key to the success of this initiative. When viewed from its social role for the community, it can be described as follows:

- Tourist ship operators: Most ship operators in Labuan Bajo welcomed the idea of implementing a hybrid PV and generator system. They acknowledged that reducing fuel consumption can reduce operational costs, especially for short-distance voyages or when the ship is at anchor. In addition, this system is considered capable of increasing tourist comfort because PV operation is quieter than conventional

generators. Operators mentioned several major challenges, such as the high initial installation costs and the need for crew training to understand the new technology. Space constraints on board the ship are also a constraint, as solar panels require a certain area that may sacrifice aesthetics or other functions. They hope that the use of hybrids can extend the life of the generator, reduce maintenance time, and improve the image of the ship as part of ecotourism. Operators are optimistic that branding the ship as "eco-friendly" will attract tourists who care about sustainability.

- Port authority: The port authority in Labuan Bajo stated that they support green energy initiatives to support the area as a sustainable tourism destination. However, they admit that specific regulations related to hybrid PV and generators on ships have not yet been widely implemented. The infrastructure at the port is still limited. There are no charging stations or energy storage facilities to support ships with hybrid technology. However, the port authority plans to improve facilities in the next few years as part of efforts to support carbon emission reduction. They are open to collaboration opportunities with ship operators and local governments to accelerate the implementation of hybrid systems. According to them, incentives in the form of reduced mooring fees for environmentally friendly ships can be an effective first step.
- Stakeholders in the energy sector: Energy experts highlight that hybrid PV and generator technology has developed rapidly. Modern solar panels have higher efficiency and are more resistant to extreme conditions, such as exposure to sea salt. Energy storage systems with lithium batteries are also considered suitable for tourist vessels. The installation costs of hybrid systems are still a major challenge, especially for small-scale operators. However, there is an opportunity to obtain funding through green credit schemes or government subsidies. Several energy companies have expressed interest in collaborating on pilot projects in Labuan Bajo. These parties emphasized that hybrid PV and gensets are an ideal transitional solution to accelerate the adoption of renewable energy in the maritime sector, while maintaining the operational flexibility of vessels.
- Stakeholders in the tourism sector: Based on experience and internal surveys, tourists visiting Labuan Bajo tend to support tourist vessels that use environmentally friendly energy. They see it as an added value that increases the attractiveness of the tourist experience. The tourism sector considers that vessels with hybrid PV and genset systems can be a unique attraction, in line with the concept of Labuan Bajo as an ecotourism destination. Sustainability-based marketing campaigns, such as the use of green technology, can improve the reputation of this area in the global market. They also see opportunities to involve local communities in the installation and maintenance of the system, thus providing a direct economic impact on the communities around the tourist area.

4. CONCLUSION

Activities in optimizing renewable energy-based electrical systems on tourist ships in Labuan Bajo with a hybrid PV and generator system show that from a technical perspective, the combination of these two energy sources can improve the reliability of the ship's electrical system by utilizing solar energy as the main source and the generator as a backup, especially when the weather is less favorable. From an economic perspective, this hybrid system can reduce long-term operational costs by reducing fossil fuel consumption, although it requires a higher initial investment for the installation of solar panels and supporting devices. Socio-culturally, the implementation of this hybrid system supports more environmentally friendly tourism practices, in line with global awareness of sustainability issues, and has a positive impact on the preservation of the marine environment which is Labuan Bajo's main asset. Thus, this hybrid system is an innovative solution to support the development of sustainable tourism in the area.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
I Made Aditya Nugraha	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
I Gusti Made Ngurah Desnanjaya		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [IMAN]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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