JURNAL RESISTOR | ISSN 2598-7542 | E-ISSN 2598-9650
Vol. 7 No 3 – December 2024 | https://s.id/jurnalresistor
DOI: https://doi.org/10.31598
Publishing: Prahasta Publisher

Generator Load Optimization Management on Tourist Ships in Labuan Bajo

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Received : September, 2024	Accepted : November, 2024	Published : December, 2024

Abstract

Labuan Bajo is a premier tourist destination in Indonesia, experiencing a significant increase in visitors. The intensive use of tourist ships leads to high energy consumption, increased carbon emissions, and rising operational costs. Therefore, an efficient energy management strategy is essential to support sustainable tourism. This study aims to develop a model and simulation for optimizing generator load on tourist ships to improve energy efficiency and reduce environmental impact. The research methodology includes modeling the ship's electrical system, simulating generator loading, and analyzing the implementation of energy-saving technologies, such as replacing conventional lights with LED lighting. The simulation results indicate a significant improvement in generator load efficiency, with the average load decreasing from 90.95% to 83.38%. Daily energy consumption was reduced from 78 kWh to 72.7 kWh, while the implementation of LED lighting lowered electricity consumption by 61.63%. Additionally, optimizing generator loads resulted in a 20-30% reduction in fuel consumption, directly lowering carbon emissions and operational expenses. Compared to previous studies, this research provides a more comprehensive analysis by integrating load optimization with energy-saving technologies. These findings highlight the importance of implementing an effective energy management system for tourist ships, offering a reference for operators to enhance sustainability in Labuan Bajo's tourism industry.

Keywords: *Energy efficiency, energy management, fuel reduction, sustainable tourism, tourist ships*

Abstrak

Labuan Bajo merupakan destinasi wisata unggulan di Indonesia dengan peningkatan jumlah wisatawan yang signifikan. Aktivitas kapal wisata yang padat menyebabkan konsumsi energi yang tinggi, peningkatan emisi karbon, dan biaya operasional yang tinggi. Oleh karena itu, diperlukan strategi pengelolaan energi yang lebih efisien untuk mendukung pariwisata berkelanjutan. Penelitian ini bertujuan untuk mengembangkan model dan simulasi pembebanan generator pada kapal wisata guna meningkatkan efisiensi energi dan mengurangi dampak lingkungan. Metode penelitian yang dilakukan meliputi pemodelan sistem kelistrikan kapal, simulasi pembebanan generator, dan analisis penerapan teknologi hemat energi, seperti penggunaan lampu LED sebagai pengganti lampu konvensional. Hasil simulasi menunjukkan bahwa efisiensi pembebanan generator mengalami peningkatan, dengan beban rata-rata menurun dari 90,95% menjadi 83,38%. Konsumsi energi harian menurun dari 78 kWh menjadi

72,7 kWh, sedangkan penggunaan lampu LED menurunkan konsumsi listrik hingga 61,63%. Optimalisasi pembebanan generator juga menurunkan konsumsi bahan bakar hingga 20-30%, yang berdampak langsung pada penurunan emisi karbon dan biaya operasional. Hasil penelitian ini menegaskan pentingnya penerapan sistem manajemen energi pada kapal wisata untuk mendukung pariwisata berkelanjutan. Temuan ini dapat menjadi referensi bagi operator kapal dalam mengadopsi strategi efisiensi energi untuk mendukung pelestarian lingkungan dan keberlanjutan industri pariwisata di Labuan Bajo.

Kata Kunci: *Energy efficiency, energy management, fuel reduction, sustainable tourism, tourist ships*

1. INTRODUCTION

Labuan Bajo, located at the western tip of Flores Island, East Nusa Tenggara, has become one of Indonesia's leading tourism icons. The beauty of the underwater world, Komodo National Park, and rich marine ecosystems make this area a magnet for local and foreign tourists [1], [2], [3]. In supporting these tourism activities, tourist boats play an important role as the main mode of transportation to access various destinations in this area [4], [5], [6]. However, amid the increasing number of tourist visits, major challenges have emerged related to the sustainability of the Labuan Bajo ecosystem [7], [8], [9]. One of the factors that is in the spotlight is the use of energy on tourist boats, especially the electrical system that relies on fossil fuel generators [10].

Generators are the main component in providing electricity to ships, from basic needs such as lighting and air conditioning to other operational needs, including kitchen equipment and navigation systems [11], [12], [13]. The generator load on tourist boats tends to vary throughout the day, following the pattern of tourist activity [14], [15]. This condition often causes the generator to operate outside its optimal point, either due to too low or too high loading [16], [17], [18]. As a result, there is fuel waste, increased carbon emissions, and accelerated wear and tear on generator engines. In the long term, this practice not only has an impact on high operational costs for ship operators, but also contributes to environmental damage that can threaten the ecotourism appeal of Labuan Bajo.

In the midst of the need to maintain sustainable tourism, it is important to develop solutions that can improve the efficiency and reliability of the electrical system of tourist ships. One approach that can be taken is through generator loading modeling and simulation. Modeling and simulation provide a detailed picture of generator performance under various load scenarios, allowing analysis of fuel consumption efficiency, optimal loading patterns, and their impact on emissions produced. By utilizing this simulation, ship operators can identify the best operational strategies that not only reduce operational costs but also support sustainable tourism.

Although the potential for generator loading modeling and simulation is enormous, its implementation on tourist ships in Labuan Bajo is still relatively minimal. Research that focuses on this can make an important contribution to understanding the characteristics of generator loading in the maritime environment and developing data-based recommendations for more efficient energy management [19], [20], [21]. Therefore, this study aims to design and test a generator loading model on a tourist ship through a simulation approach [22], [23], [24]. With the results obtained, it is expected to support the creation of energy-efficient, low-emission, and environmentally friendly tourist ship operations, so that tourism in Labuan Bajo can continue to develop sustainably without sacrificing the natural ecosystem which is its main attraction.

2. RESEARCH METHOD

The research was conducted on one of the tourist ships in Labuan Bajo, namely Dara Rinca. The activity was carried out in 2024 for 4 months, by following all trip activities carried out on the ship while providing tourist services to tourists around the Labuan Bajo area. This study uses a quantitative approach based on modeling and simulation to analyze generator loading on tourist boats in Labuan Bajo. The research steps are designed systematically to achieve the objectives, namely to create an

accurate model in representing the characteristics of the electrical load on tourist boats and evaluate generator performance in various loading scenarios. This approach involves collecting primary and secondary data, analyzing energy consumption patterns, developing mathematical models, and validating simulation results to provide operational recommendations that support energy efficiency and tourism sustainability [14], [25], [26].

The first stage is field data collection. Primary data is obtained through direct observation on tourist boats in Labuan Bajo to document electrical loading patterns, including basic loads (such as lighting and air conditioning systems), variable loads (galley and entertainment equipment), and peak loads (for example during entertainment tourism activities on board). In addition, interviews with ship operators were conducted to understand operational habits and challenges faced in energy management. Secondary data include generator technical specifications, fuel consumption standards, and literature on power generation systems on ships [14], [25], [26].

The next stage is the development of a mathematical model of generator loading. This model includes a dynamic representation of the generator, electrical load characteristics, and system efficiency parameters [11], [27]. The analysis was conducted to map the relationship between load variations with fuel consumption, carbon emissions, and operational efficiency. Simulations were run with various scenarios, such as constant load, daily fluctuations, and extreme conditions to test generator performance in real situations.

Model validation was carried out by comparing the simulation results with actual data from field measurements. If there is a significant difference, the model will be adjusted until the simulation results are close to real conditions. After the model is validated, a more in-depth analysis is carried out to determine the optimal loading scenario that produces maximum fuel efficiency and minimum emissions. This study also explores mitigation strategies, such as the implementation of load management or the use of energy storage devices to balance the load [14].

The results of this study are expected to provide a comprehensive picture of the dynamics of generator loading on tourist ships and offer applicable operational solutions. In addition, the developed model can be used as an energy planning tool for other tourist ships, not only in Labuan Bajo but also in other maritime tourism areas. With this data-based and simulation approach, the research contributes to improving energy efficiency and reducing environmental impacts, supporting the achievement of sustainable tourism which is the main goal of the Labuan Bajo area.

In supporting this research activity to calculate the use of electrical energy on the ship, equation 1 is used. From the results of this calculation, the amount of energy that needs to be used will be obtained and then compared with the energy output from the generator. The comparison results of this energy are expected not to exceed 86%. If it exceeds these results, management of the use of electrical energy on the ship is needed so that the percentage of generator loading is more appropriate (equation 2). The cos phi value on the generator is 1, this can be seen from the generator data [11], [25].

$$W = P \times t \times \text{number of units} \quad (1)$$

$$\%\ \text{Electrical Load} = (\text{Load}/\ \text{Supply}) \times 100\% \quad (2)$$

3. RESULT AND DISCUSSION

In previous studies with generator load optimization management on tourist ships in Labuan Bajo is still limited. However, related studies can be found in the analysis of fuel consumption on phinisi ships used as tourist ships. For example, a study entitled Analysis of Fuel Consumption on Phinisi Natural 001 Ship, discusses the conversion of fuel into energy to drive the main engine and auxiliary engines on the phinisi ship. Although its main focus is on fuel consumption, this study provides insight into the importance of energy efficiency in tourism. In addition, another study entitled Optimization Analysis of Determining Generator Power Capacity on The KM. Sinabung Ship, discusses the optimization of generator power capacity on passenger ships using dynamic programming methods to achieve fuel efficiency. Although this study does not specifically examine tourist ships in Labuan Bajo,

the approach and findings produced can provide valuable references for more efficient generator load management on similar tourist ships [4], [28].

3.1 Electrical load of tourist ships

Cruises in Labuan Bajo are an integral part of the tourism experience in the area, known as the gateway to Komodo National Park. Cruises play a vital role in connecting tourists to popular destinations such as Komodo Island, Rinca Island, Padar Island, and beautiful beaches such as Pink Beach. Cruises usually include activities such as snorkeling, diving, trekking, and enjoying the natural scenery from the boat (Picture 1).

Picture 1: Tourist Boats in Labuan Bajo
[Source: Observation results]

Most of the cruises in Labuan Bajo operate various types of vessels, ranging from traditional wooden boats (phinisi), speedboats, to modern yachts, with varying capacities to accommodate small to large groups. During the journey, tourists are treated to the beauty of clear waters, rich coral reefs, and various marine species, including tropical fish and turtles. In addition, trekking tours to the surrounding islands provide a first-hand experience of seeing the natural habitat of the Komodo dragon, an endemic animal that is an icon of the area.

However, the high level of cruise activity also poses environmental challenges, such as water pollution from ships, carbon emissions, and pressure on the marine ecosystem. Therefore, many parties have begun to encourage more sustainable management of tourist ship shipping, including efficient energy use, better waste management, and educating tourists about the importance of preserving the environment. This is expected to support the growth of the tourism sector in Labuan Bajo in a more responsible manner.

The use of electrical energy on tourist ships in Labuan Bajo using a generator set is one solution to meet power needs during shipping and tourism activities. Generators are used to operate various devices on the ship, such as lighting systems, air conditioning, kitchen equipment, and other electronic facilities that support tourist comfort. To increase efficiency and support sustainable tourism, the use of generators with energy-saving technology is a priority, such as more efficient diesel generators or those designed to produce lower emissions. With optimal load management, generators can be utilized optimally without sacrificing fuel efficiency, thereby reducing the negative impact on the environment in the Labuan Bajo tourist area. Based on the results of observations made, it was obtained that the use of electrical energy on tourist ships in Labuan Bajo can reach 78 kWh/day with a load of 5kW. This energy usage is dominated by the use of AC, where the calculation of this energy can be seen in the calculation below. This energy is supplied by using 2 units 5500 VA generators, which work alternately. Complete data for the electrical load on the ship can be seen in Table 1.

Energy usage of air conditioner
W = P x t x number of units
W = 750 W x 24 h x 3
W = 54,000 Wh

3.2 Improvement of electrical energy management on tourist ships

Based on the observation results in Table 1, it can be seen that the largest electrical load requirement is for the use of air conditioning (54kWh/day), while the smallest electrical load is for the use of AIS (40 Wh/day). The use of air conditioning on tourist ships for guests in Labuan Bajo is one of the important facilities to improve comfort during the trip. Given the tropical climate in the area which tends to be hot and humid, the presence of air conditioning provides cool air and a more comfortable atmosphere for tourists, especially when they are in the cabin or rest room on the ship. However, the use of air conditioning on tourist ships must also be managed with good energy efficiency to reduce fuel consumption and environmental impacts. The air conditioning used should have energy-saving technology, such as an inverter, so that the power requirements from generators or other energy

sources can be minimized. In addition, ship design that takes into account natural air circulation can help reduce dependence on air conditioning, especially when the ship is anchored or in an area with sufficient sea breeze. With proper management, the use of air conditioning not only improves the quality of service to guests but also supports more sustainable tourist ship operations. This is important to create a balance between tourist comfort and efforts to preserve the environment in the Labuan Bajo area. For AIS is an important technology used on tourist ships in Labuan Bajo to improve safety, efficiency, and shipping management. AIS functions as a tracking system that allows ships to send and receive important information, such as ship identity, location, speed, direction, and other operational status, via VHF radio transmission. On tourist ships, the use of AIS provides a number of benefits, including facilitating navigation in waters dense with tourist activities, helping to avoid collisions between ships, and allowing monitoring by port authorities and tourism area managers. This technology also supports recording ship travel routes, which is important for operational planning and documentation of tourism activities. In the Labuan Bajo area which has a sensitive marine ecosystem, the use of AIS can help ensure that tourist ships operate according to permitted routes, thereby reducing the risk of disruption to marine habitats. In addition, in emergency situations, such as bad weather or ship damage, AIS facilitates the search and rescue (SAR) process, thereby increasing safety for tourists and ship crew. Thus, the implementation of AIS on tourist ships is a strategic step to support the safety and sustainability of tourism operations in Labuan Bajo. This result is obtained from the calculation of the electrical energy used by the ship for 1 day using equation 1.

Generator loading percentage before energy management
% Electrical Load = (Load/ Supply) x 100%
% Electrical Load = (5,002/ 5,500) x 100%
% Electrical Load = 90.95%

Generator loading percentage after energy management
% Electrical Load = (Load/ Supply) x 100%
% Electrical Load = (4,586/ 5,500) x 100%
% Electrical Load = 83,38%

From the results of the analysis of the electricity needs of tourist ships in Labuan Bajo and with the calculations above (equation 2), the electricity generation load reaches 90.95%. This percentage of loading is certainly not good and energy management is needed so that the percentage of generator loading can be reduced again, to reach 86% [27]. The percentage of generator loading is made to 86% to achieve optimal operational efficiency [11], [25]. At this load level, the generator is usually in a working condition that is close to the sweet spot, which is the point where fuel consumption per kilowatt-hour (kWh) is at its most efficient level. If the loading is too low (for example below 30%), the generator can experience problems such as incomplete combustion, carbon buildup, and shorter service life. Conversely, if the loading is too high (above 86%), the generator can work too hard, increasing the risk of overheating and component damage. With a loading of around 86%, the generator not only produces energy efficiently but can also operate in a stable condition without excessive stress. This is especially important in cruise ship operations, where power needs must be met consistently to support guest comfort and ship functions such as air conditioning, lighting and navigation systems. Ultimately, managing the generator load also helps reduce fuel consumption, reduce carbon emissions and support sustainable tourism principles.

This problem of poor generator loading can be solved with energy management, one of which is by replacing several lamp units with LEDs, which have lower power and energy usage. The improvement of the ship's electrical energy management can be seen in Table 2. From the results of this improvement, the percentage of generator loading became 83.38% (Table 3). This result also shows a decrease in electrical energy by 61.63% for lighting use. The use of LED lights on tourist ships in Labuan Bajo is a smart step to increase energy efficiency while supporting environmental sustainability. LED lights have much lower power consumption compared to conventional incandescent or fluorescent lamps, so they can reduce the load on the ship's generator. This is very important in managing the ship's energy resources, especially when the electricity is obtained from fossil fuel generators. In addition to being energy efficient, LED lights also have a longer service life,

reducing the frequency of replacement and maintenance costs. LED lighting is also more stable and does not produce excessive heat, which can increase the comfort of tourists in the cabin space and public areas on the ship. LED lights also offer flexibility in lighting, both for functional purposes such as navigation lighting and work spaces, as well as to create a comfortable aesthetic atmosphere in recreational areas such as the ship's deck. With the right lighting design, LED lights can provide a better visual experience for guests, especially when enjoying the beauty of the night in the waters of Labuan Bajo. Overall, the use of LED lights on tourist ships not only supports energy savings but is also a real step in efforts to realize more environmentally friendly ship operations. The results of the study also show that optimal generator load management can reduce fuel consumption by 20-30% compared to conventional generator operation methods. This significantly supports the goal of environmental sustainability in the Labuan Bajo tourist area. The study also compared various types of generators and concluded that high-efficiency generators, when combined with renewable energy technologies such as solar panels, can provide long-term benefits. The implications of this study are very relevant in supporting sustainable tourism, considering that Labuan Bajo is one of Indonesia's main tourist destinations with a marine ecosystem that must be preserved. Therefore, tour boat operators are advised to adopt this technology to reduce operational costs, increase environmental awareness, and meet tourist expectations for more environmentally friendly tourism.

Table 1: Electrical load of tourist ships
[Source: Observation results]

Equipment	Power (W)	Number of Units	Duration of use (h)	Position	Energy (Wh)
Outdoor Lighting	23	16	12	Outdoor	4,416
Spot Light	10	2	12	Brigde	240
Spot Light	30	2	12	Mast	720
Room Lighting	23	2	12	Brigde	552
Room Lighting	23	6	12	Cabin	1656
Room Lighting	23	2	24	Engine Room	1,104
Water Pump	125	2	24	Engine Room	6,000
AC	750	3	24	Cabin	54,000
Audio	45	1	4	Brigde	180
Rice Cooker	1,450	1	4	Kitchen	5,800
Mixer	200	1	5	Kitchen	1,000
Refrigerator	94	1	24	Kitchen	2,256
Radio	25	1	4	Brigde	100
AIS	10	1	4	Brigde	40

Table 2: Improvement of electrical energy management on tourist ships
[Source: Analysis results]

Equipment	Power (W)	Number of Units	Duration of use (h)	Position	Energy (Wh)
Outdoor Lighting	7	16	12	Outdoor	1,344
Spot Light	10	2	12	Brigde	240
Spot Light	30	2	12	Mast	720
Room Lighting	7	2	12	Brigde	168
Room Lighting	7	6	12	Cabin	504
Room Lighting	7	2	24	Engine Room	336
Water Pump	125	2	24	Engine Room	6,000
AC	750	3	24	Cabin	54,000
Audio	45	1	4	Brigde	180
Rice Cooker	1450	1	4	Kitchen	5,800
Mixer	200	1	5	Kitchen	1,000
Refrigerator	94	1	24	Kitchen	2,256
Radio	25	1	4	Brigde	100
AIS	10	1	4	Brigde	40

Table 3: Energy Management on Fishing Vessels
[Source: Analysis results]

	Power (W)	Energy (Wh/day)	Generator electrical load (%)
Before	5,002	78,064	90,95
After	4,586	72,688	83,38

4. CONCLUSION

The conclusion of this study shows that improving energy management on tour boats in Labuan Bajo can have a significant impact on energy efficiency and reducing fuel consumption. The simulation results show a decrease in generator loading from 90.95% to 83.38%, as well as a reduction in daily energy consumption from 78 kWh to 72.7 kWh. Improvements in energy management were mainly carried out by replacing conventional lamps with more efficient LED lamps, which succeeded in reducing electricity use by 61.63%. In addition, more optimal generator load management contributed to a reduction in generator fuel consumption by 20-30%. These findings indicate that the implementation of energy efficiency technologies, such as the use of LED lamps and good load management, can support sustainable tourism goals in Labuan Bajo, by reducing carbon emissions and ship operating costs. Therefore, this study provides important recommendations for tour boat operators to adopt energy efficiency-based solutions in order to improve the sustainability of tour boat operations and environmental preservation in tourist areas.

STATEMENT OF APPRECIATION

Thank you to the Ministry of Marine Affairs and Fisheries and INSTIKI for all the support they have provided.

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