Energy Saving Potential of Hybrid Propulsion System for Fishing Vessels in Indonesia

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Abstract. Indonesia, as the largest archipelagic country in the world, has a fishing vessel fleet dominated by conventional diesel engine-based propulsion systems. The high use of fossil fuels on these fishing vessels causes significant greenhouse gas emissions and unstable operating costs due to fluctuations in fuel prices. This study explores the potential for energy savings and emission reductions from the implementation of hybrid propulsion systems on fishing vessels in Indonesia. Using literature analysis and case studies, this study compares energy efficiency, fuel consumption, and emissions in conventional and hybrid propulsion systems. The results show that the implementation of a hybrid system can reduce energy consumption by up to 29.4%, reduce fuel consumption by up to 25%, and reduce CO_2 emissions by up to 23% per trip compared to conventional vessels. A hybrid diesel-electric propulsion system with renewable energy integration is the optimal configuration for small to medium-scale fishing vessels in Indonesia. This study provides recommendations for ideal propulsion designs based on vessel operational characteristics, and supports the transition to more environmentally friendly and sustainable electricity technology in the Indonesian maritime sector.

Keywords: Hybrid propulsion, fishing vessels, energy efficiency, emission reduction, Indonesian

1 Introduction

Indonesia, as the largest archipelagic country in the world, has more than 17,000 islands and a coastline of more than 108,000 km. This geographical condition makes Indonesia one of the countries with the largest fisheries sector in the world, which plays a crucial role in food security, the economy, and the livelihoods of millions of people [1]. Indonesia, as the country with the longest coastline in the world, has high solar energy potential with an average solar radiation of 4.8 kWh/m²/day, but this potential was not adequately explored to assist the fishing industry [2]. Meanwhile, most of the fishing vessel fleet in Indonesia still uses conventional diesel engine-based propulsion systems, which have high fuel consumption and have a negative impact on the environment, including producing greenhouse gas emissions (CO_2), NO_x, and SO_x [3]. At the same time, dependence on fossil fuels also makes operational costs unstable, given the fluctuations in fuel prices influenced by the global market [4].

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This condition encourages the need for innovation and transformation towards more efficient and environmentally friendly propulsion technology, one of which is the application of a hybrid propulsion system on fishing vessels. This hybrid technology utilizes a combination of diesel engines, batteries, and renewable energy sources, such as solar panels or wind turbines, which can optimize energy use and reduce emissions [5]. In a number of case studies, including those involving Brazilian longline-fishing fleets, hybrid systems aboard fishing vessels are being demonstrated to save fuel usage by as much as 30% [4]. Furthermore, it has been demonstrated that using renewable energy sources aboard ships, such solar power, enhances ship operations in coastal regions and shallow waters with high levels of sunshine exposure [1].

The ideal hybrid propulsion system design for fishing vessels in Indonesia needs to consider the operational characteristics of the vessel, including the voyage profile, fishing pattern, and power requirements [6]. For example, a hybrid system that utilizes lithium-ion batteries as energy storage can provide higher efficiency for small to medium vessels operating in coastal areas [7]. In small-scale fishing vessels, the use of intelligent energy management systems can further optimize energy use by adjusting the switching of power sources based on load conditions and the vessel's operating profile [5]. Recent studies have shown that the application of a hybrid propulsion system can not only reduce emissions and fuel consumption, but also increase engine life and reduce maintenance costs [7]. In addition, a hybrid propulsion system provides flexibility for vessels to operate using electric power at low speeds or during maneuvering, which is very important for maintaining the sustainability of marine ecosystems [8]. The use of batteries charged with renewable energy also allows vessels to operate with zero emissions during the fishing process, thereby increasing energy independence [9], reducing environmental impacts and increasing the economic value of vessels [6].

There is a substantial study vacuum concerning Indonesian-fishing vessels, despite the fact that hybrid propulsion systems have been extensively studied and used in a variety of vessel types. Most previous studies have focused more on cargo vessels and cruise ships, which different operational profiles and energy consumption patterns have compared to fishing vessels [5]. In addition, research on hybrid propulsion systems on fishing vessels often does not consider the integration of renewable energy, such as solar and wind, which are actually very relevant for vessel operations in tropical waters such as Indonesia [1]. Therefore, this study aims to explore the potential energy savings and environmental benefits of implementing hybrid propulsion systems on fishing vessels in Indonesia. By comparing various hybrid designs to conventional propulsion systems, this study will evaluate fuel consumption, emissions, and energy efficiency under various operational scenarios. The results of this study are expected to provide valuable insights into the feasibility of transitioning to hybrid propulsion systems for fishing vessel fleets in Indonesia, as well as supporting the development of a more sustainable and resilient fisheries sector [1].

2 Methodology

This research began with the collection of literature from various scientific journals, technical reports, and relevant international case studies related to the implementation of hybrid propulsion systems, energy saving strategies, and renewable energy integration on fishing vessels. After the literature was collected, an analysis was conducted to identify hybrid technology trends, energy saving potential, emission reductions, and implementation challenges in the maritime sector globally. The findings were then grouped based on relevant categories, such as types of hybrid propulsion systems, energy management strategies, and energy performance and environmental impact evaluation results, which were then synthesized to provide a comprehensive understanding of the advantages and disadvantages of various hybrid system configurations in various countries. Based on the results of the synthesis, an evaluation of the feasibility of implementing hybrid propulsion systems on fishing vessels in Indonesia was carried out by considering geographical conditions, ship operational patterns, and applicable regulations. The final stage is the preparation of recommendations for the optimal hybrid propulsion system design along with its implementation strategy in Indonesia, including the integration of renewable energy and energy saving strategies, as a guide for the development of hybrid technology in the Indonesian maritime sector. If the process of retrofitting conventional ships into electric ships is carried out, it requires calculation of the load profile and simulation of the capacity of the electric motor and battery that are in accordance with the operational needs of anglers [10].

3 Result and Disscussion

This section presents the results of the comparison of energy and fuel consumption between conventional and hybrid vessels, as well as an evaluation of energy savings that can be achieved through the implementation of a hybrid propulsion system. In addition, an analysis of the impact of emissions caused by each system is carried out, to understand the extent to which hybrid technology can reduce greenhouse gas emissions such as CO_2, NO_x, and SO_x. The discussion also includes the most suitable hybrid propulsion design for application on fishing vessels in Indonesia, taking into account energy efficiency, operational costs, and environmental aspects in the fisheries sector.

3.1 Potential Savings and Emissions of Hybrid Fishing Vessels

The energy consumption of hybrid vessels was recorded at 600 kWh per trip, which is lower than that of conventional vessels, which reached 850 kWh, resulting in energy savings of around 29.4%. This reduction is due to the use of batteries during low-load operations, which allows the vessel to be more efficient in using energy when conditions do not require full power. In addition, the fuel consumption of hybrid vessels is also lower, with a decrease of up to 25% from 2,808.6 liters on conventional vessels to 2,100 liters. The use of batteries on hybrid vessels has proven to be optimal, especially during low-speed operations, where battery energy consumption reaches 240 kWh per trip, thus reducing dependence on diesel engines. Fuel efficiency also increased from 0.35 L/kWh on conventional vessels to 0.28 L/kWh on hybrid vessels, reflecting a reduction in fuel consumption per unit of energy used. Table 1 shows that the hybrid system on fishing vessels can not only save energy and fuel, but also increase operational efficiency under low-load and low-speed conditions.

Table 1. Energy Savings on Hybrid Fishing Vessels

Category	Conventional Fishing Vessels	Hybrid Fishing Vessels	Savings	Ref.
Energy Consumption (kWh/trip)	850	600	29.4%	[11]
Fuel Consumption (Liter/trip)	2,808.6	2,100	25%	[12]
Fuel Efficiency (L/kWh)	0.35	0.28	20%	[12]
CO_2 emissions (kg/trip)	650	500	23%	[13]
Fuel Cost (USD/trip)	150	112.5	25%	[14]

Meanwhile, the implementation of the hybrid propulsion system has been proven able to significantly reduce greenhouse gas emissions compared to conventional ships. A 23% reduction in CO_2 emissions was achieved thanks to the use of batteries during low-speed operations, which reduces dependence on fossil fuel combustion and reduces the amount of CO_2 emissions released into the atmosphere. In addition, NO_x emissions, which are generally produced by diesel engines when maneuvering and operating at low speeds, were also reduced by 25% on hybrid ships. This shows that the use of batteries during maneuvering and low-speed conditions can reduce NO_x emissions that usually increase due to incomplete combustion in diesel engines. Furthermore, SO_x emissions originating from the sulfur content in the fuel also decreased significantly by 44.4%. This decrease shows that hybrid ships not only reduce carbon emissions, but also succeed in reducing emissions of other pollutants that have a negative impact on the marine environment. The reduction in emissions not only contributes to improving air quality around the shipping area, but also supports the sustainability of marine ecosystems that are sensitive to pollution. Therefore, these results provide strong evidence that the implementation of a hybrid system can overall reduce the environmental impacts generated by the maritime sector and support global efforts in mitigating climate change, as summarized in Table 2.

Table 2. Comparison of Emissions between Conventional and Hybrid Fishing Vessels

Emission Parameters	Conventional fishing vessels	Hybrid fishing vessels	Reduction	Ref.
CO_2 emissions (kg/trip)	650 kg	500 kg	23%	[13]
NO_x emissions (kg/trip)	5.1 kg	3.8 kg	25%	[3]
SO_x emissions (kg/trip)	0.9 kg	0.5 kg	44,4%	[13]

3.2 Potential Design of the Most Suitable Propulsion System for Fishing Vessels in Indonesia

The most suitable hybrid propulsion system design for fishing vessels in Indonesia is based on operational needs and characteristics of the waters. Based on the literature, the optimal hybrid propulsion design is a combination of a diesel-electric propulsion system and renewable energy integration. This system uses a diesel engine as the main power source when the vessel is operating at full load, while electric power from the battery is used for maneuvering in port, low-speed operations, and when the vessel is anchored [11]. The use of renewable energy such as solar PV (Photovoltaic) to charge the battery during operation can also reduce fuel consumption at low load conditions [11]. This integration not only provides better energy efficiency but also supports environmental sustainability by reducing emissions [13].

The main advantage of a diesel-electric hybrid propulsion system with lithium-ion batteries is the flexibility in operation at various load and speed conditions without sacrificing energy efficiency [13]. At low load conditions or low speed operations, this system allows the use of electric power from the battery, thereby reducing fuel consumption that is usually inefficient in conventional diesel engines [13]. In addition, the significant reduction in greenhouse gas emissions such as CO_2, NO_x, and SO_x makes this system more environmentally friendly and suitable for application in water areas that are sensitive to pollution [13].

Therefore, a diesel-electric hybrid system with renewable energy integration is an optimal choice for fishing vessels in Indonesia, because it not only reduces operational costs but also has a positive impact on environmental sustainability. Further evaluation of the hybrid propulsion system design can be divided into several main configurations: serial hybrid, parallel hybrid, and diesel-PV electric hybrid [11]. In the serial hybrid configuration, a diesel engine is used to drive a generator which then produces electricity for the electric motor that drives the ship's propeller. The advantage of this system is the ability to turn off the diesel engine at low speed and only use the battery as the main power source, making it suitable for small to medium-sized ships (5-15 tons) with a distance that is not too far [11]. In the parallel hybrid system, the diesel engine and electric motor can drive the propeller simultaneously or separately, providing flexibility in using diesel power at high loads and electric power at low loads. This system is more suitable for ships with operating patterns that vary between low and high speeds [13]. Meanwhile, in the diesel-electric hybrid, the generator driven by the diesel engine provides electric power for the propulsion motor, while the battery is recharged when the diesel engine is operating, providing flexibility in using electric power during light operations or when anchored. More details have been illustrated in Figure 1. These three designs are most suitable for ships that frequently operate in coastal areas and require frequent maneuvering in ports [11].

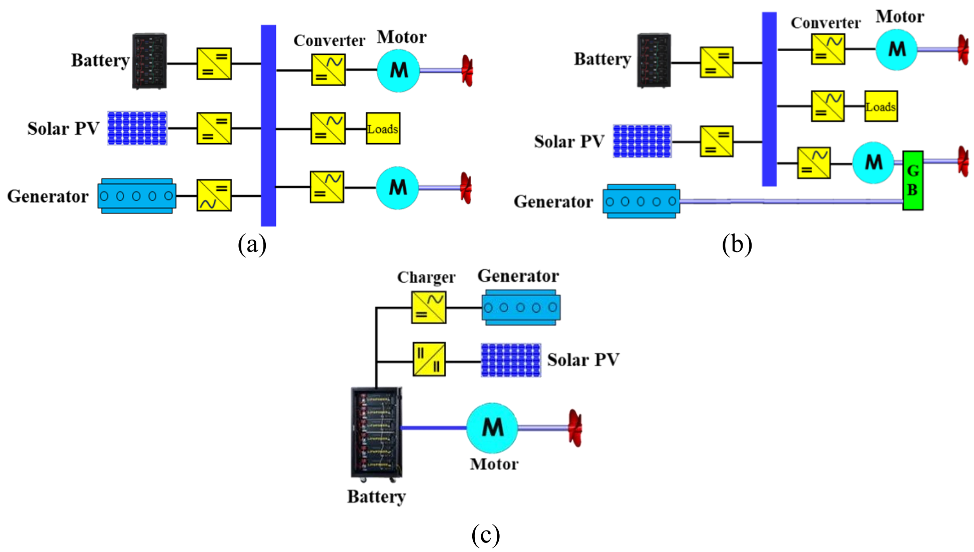

Fig. 1. Hybrid Fishing Vessel Propulsion System, (a) serial hybrid, (b) parallel hybrid, and (c) diesel-PV electric hybrid.

3.3 Performance evaluation of hybrid propulsion systems on Fishing Vessels

Table 3 shows that hybrid ships have fuel efficiency advantages in various operational conditions compared to conventional ships. At full load conditions, the fuel efficiency of hybrid ships is recorded at 0.28 L/kWh, higher than conventional ships which reach 0.35 L/kWh. This shows that even at high loads, the use of a hybrid system can reduce fuel consumption per unit of energy used. Meanwhile, at low load conditions, hybrid ships can operate by relying only on electric power, resulting in a fuel efficiency of 0.25 L/kWh compared to conventional ships whose fuel consumption reaches 0.40 L/kWh. This efficiency is increasingly evident in low speed operations below 5 knots, where hybrid ships use around 320 liters of fuel per trip, much lower than conventional ships which reach 450 liters per trip. At medium speeds between 5 and 10 knots, hybrid ships still show better efficiency due to lower fuel consumption. Even at high speeds above 10 knots, hybrid vessels can maintain their efficiency advantage thanks to the optimal combination of diesel engines and electric motors. These results show that hybrid propulsion systems are not only superior at low-load and low-speed operating conditions, but are also able to improve energy efficiency at full load and high speed, thus providing significant benefits in various fishing vessel operational scenarios.

Table 3. Performance Evaluation of Hybrid Propulsion System of Fishing Vessels

Operational Conditions	Diesel	Diesel-Electric	Ref.
Full Load	0.35 L/kWh	0.28 L/kWh	[12]
Low Load	0.4 L/kWh	0.25 L/kWh	[4]
Speed < 5 knots	450 L	320 L	[13]
Speed 5-10 knots	800 L	600 L	[11]
Speed > 10 knots	1100 L	850 L	[14]

The term trip on a fishing vessel refers to the operational cycle that includes departure from the port, the fishing process in the operating area, until the vessel returns to the port. The distance traveled by the vessel can vary depending on the type of vessel and the area of operation, where vessels measuring 9-15 tons have around 50-200 km per trip, while vessels weighing 15-30 tons can reach 300-500 km per trip, especially if operating on the high seas [11]. The duration of the trip usually ranges from 3-7 days for small vessels and 10-14 days for large vessels, with fishing cycles carried out several times in one trip depending on weather conditions and the amount of catch [14]. In addition to distance and duration, vessel size also affects energy consumption and operational efficiency. Larger vessels tend to require more fuel, so the potential efficiency of the hybrid system is more significant. In low-speed operating conditions, hybrid vessels can rely on electric power to reduce fuel consumption by up to 25% compared to conventional vessels that only use diesel engines [13]. This shows that hybrid vessels are superior in energy efficiency, especially in operating phases that require low power such as maneuvering in ports or when drifting in fishing areas.

4 Conclusion

This study shows that the application of hybrid propulsion systems on fishing vessels in Indonesia can provide significant benefits in terms of energy efficiency and emission reduction. The use of a diesel-electric hybrid system with renewable energy integration can reduce energy consumption by up to 29.4% and fuel consumption by up to 25%, as well as reduce CO_2 emissions by up to 23% compared to conventional vessels. This efficiency is achieved using batteries at low speed and light load operations, which significantly reduces dependence on diesel engines. Considering the characteristics of Indonesian waters, the integration of renewable energy such as solar panels and the use of lithium-ion batteries is recommended as an optimal solution. The results of this study are expected to encourage the adoption of hybrid technology in the Indonesian fisheries sector that is more sustainable and environmentally friendly.

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