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The use of Savonius wind turbines to support electricity needs on passenger ships in Maluku waters

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Abstract
The maritime industry in Indonesia, especially within the Maluku region, is significantly dependent on passenger vessels to facilitate inter-island travel. This dependency, while essential for connectivity, leads to considerable fossil fuel consumption and exacerbates environmental pollution. In light of these challenges, this study explores the potential of integrating Savonius-type vertical-axis wind turbines (VAWTs) as a supplementary renewable energy source. The aim is to alleviate the electricity demands and reduce the fuel reliance of passenger ships operating in the waters of Maluku, thereby promoting a more sustainable maritime transport system. To achieve this, the research employs a multifaceted approach that includes wind data analysis, computational fluid dynamics (CFD) simulations, and detailed profiling of onboard electrical loads. The analysis of wind speed data reveals that the Maluku waters experience adequate low-to-moderate wind conditions, ranging from 3 to 6 m/s, which are conducive for the operation of Savonius turbines. Notably, the apparent wind generated by the movement of the vessels further enhances the efficiency of these turbines. A configuration utilizing two turbines is projected to produce an average of 4 to 6 kWh per day, which could satisfy approximately 5 to 7% of the electrical requirements of the ship, thereby contributing to a reduction in fossil fuel usage. The findings of this study underscore the significant potential of Savonius wind turbines in contributing to hybrid renewable energy systems aimed at fostering sustainable maritime transport in eastern Indonesia. Furthermore, the research advocates for the integration of additional renewable energy sources, such as solar photovoltaic (PV) systems and battery storage solutions, to optimize the utilization of renewable energy onboard. This holistic approach not only enhances energy efficiency but also aligns with broader environmental goals, paving the way for a greener future in the maritime sector of Indonesia.

Keywords: Savonius wind turbine, passenger ship, renewable energy, Maluku waters, maritime sustainability, vertical-axis wind turbine, hybrid power system.

Introduction

Indonesia, as the largest archipelagic nation in the world, heavily relies on maritime transportation. (Djunarsjah & Putra, 2021) [3]. The Maluku Islands, known for their dispersed geography, are particularly dependent on passenger ships for inter-island connectivity. However, this dependence has brought about increasing concerns regarding fuel consumption, emissions, and energy sustainability, especially for smaller or medium-sized passenger vessels. (Louhenapessy *et al.*, 2024; Nurhayati & Purnomo, 2017) [8, 12].

The shift towards sustainable energy sources in maritime operations is gaining momentum globally. Wind energy, as a renewable and abundant resource in tropical maritime climates, presents an attractive alternative. (Tillig & Ringsberg, 2020) [15]. Among the various wind turbine technologies available, the Savonius wind turbine stands out for its simplicity, low-cost construction, and ability to operate effectively in low wind speed conditions—characteristics that align well with maritime operational constraints. (Wang *et al.*, 2022) [16].

This study explores the feasibility, design integration, and performance of Savonius vertical-axis wind turbines (VAWTs) on passenger ships operating in Maluku waters. Unlike horizontal-axis turbines, Savonius turbines can capture wind from any direction and are mechanically simpler, making them suitable for marine environments where space and maintenance access may be limited. (Manne & Zhou, 2019) [9].

Traditional power systems utilized in passenger vessels predominantly rely on fossil fuels, leading to significant operational expenses and considerable environmental pollution. Although there is a growing trend towards hybrid systems that incorporate solar energy and battery storage, the potential of wind energy has not been thoroughly investigated within the Indonesian maritime sector. This oversight presents an opportunity to explore alternative energy sources that could enhance sustainability and reduce reliance on fossil fuels, thereby addressing both economic and ecological concerns. (Dhamotharan *et al.*, 2015; Hui *et al.*, 2018) [2, 6].

However, the integration of wind turbine technology into existing ship designs poses several challenges that must be addressed for successful implementation. (Kuczyński *et al.*, 2024) [7]. One of the primary hurdles is the adaptation of wind turbine systems to fit seamlessly within the structural framework of the vessel. Additionally, it is crucial to conduct thorough assessments of wind availability and the efficiency of turbines along typical maritime routes to ensure optimal performance. Furthermore, a comprehensive evaluation of how much wind energy can realistically contribute to the ship's electrical load is necessary to determine the feasibility and effectiveness of this renewable energy source in maritime operations. (Reina & Foglia, 2019; Tillig & Ringsberg, 2020) [14, 15].

The primary objective of this study is to assess the viability of utilizing Savonius wind turbines for generating electricity aboard passenger vessels operating in the Maluku region. This involves not only evaluating the technical and economic feasibility of such an implementation but also designing an optimal configuration for the placement of these turbines on the ships to maximize efficiency and energy capture. (globalwindatlas.info, 2024) [5]. Furthermore, the research will include modeling and simulating the expected energy output based on the specific wind conditions prevalent in the area, allowing for a comprehensive understanding of the potential energy yield. Finally, a thorough analysis will be conducted to determine how effectively the generated electricity can meet the daily electrical demands of the vessels, thereby contributing to a more sustainable and efficient energy solution for maritime operations in Maluku. (Louhenapessy *et al.*, 2024; Pelupessy & Manuhutu, 2019) [8, 13].

This research seeks to advance the sustainable development of maritime transportation in Indonesia by proposing an innovative energy system designed to minimize fuel consumption, reduce harmful emissions, and facilitate the integration of renewable energy sources within ship operations. By focusing on alternative energy solutions, the study aims to address the pressing environmental challenges faced by the maritime sector, which is often heavily reliant on fossil fuels. The introduction of such a system not only promises to enhance the efficiency of maritime transport but also aligns with global efforts to combat climate change and promote cleaner energy practices. Through this initiative, the research aspires to pave the way for a more sustainable future in Indonesia's maritime industry, ultimately contributing to the broader goals of environmental stewardship and energy transition.

Methodology

1. Study Area: Maluku Waters

The waters of Maluku are defined by a tropical maritime climate, which is influenced by seasonal trade winds that contribute to a relatively stable environment characterized by low to moderate wind speeds. This climatic condition plays a significant role in maritime navigation and local weather patterns. To analyze these wind conditions, data was sourced from NASA's POWER Data Access Viewer alongside information from the Indonesian Meteorology, Climatology, and Geophysical Agency (BMKG). The focus of this analysis was on the primary inter-island route connecting Ambon and Tual, which spans approximately 352 nautical miles.

Inter-island routes (Ambon–Tual)

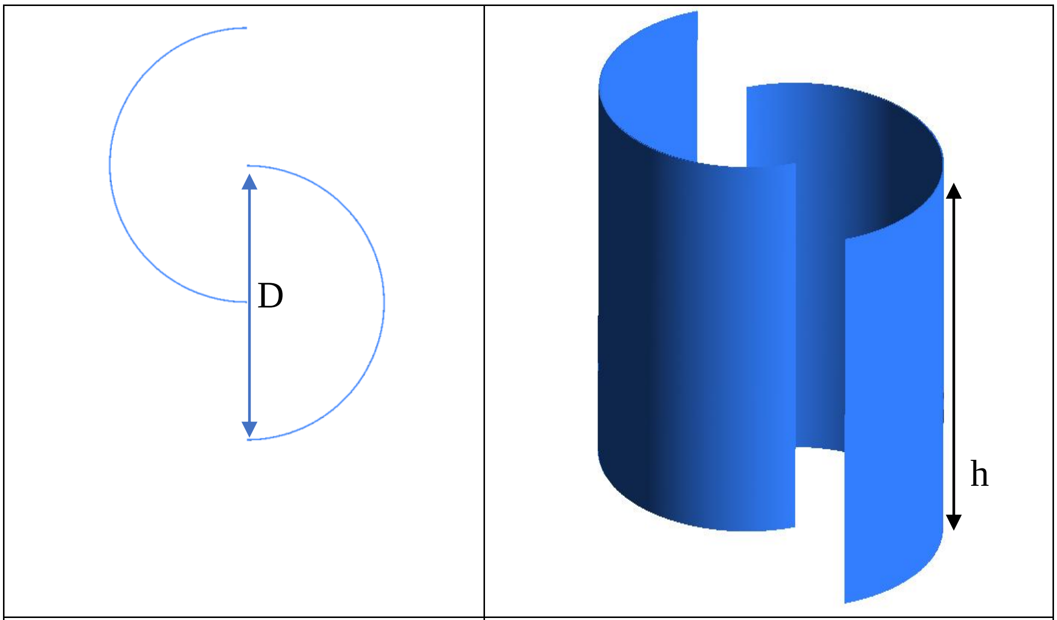
The wind dynamics in this region are crucial for various maritime activities, including fishing, shipping, and tourism. The consistent wind patterns not only affect navigation but also influence the ecological balance of the surrounding marine environment. By utilizing comprehensive wind data, stakeholders can make informed decisions that enhance safety and efficiency in maritime operations. The collaboration between international and local meteorological agencies underscores the importance of accurate weather forecasting and climate monitoring in ensuring the sustainability of Maluku's maritime resources.

2. Turbine Design

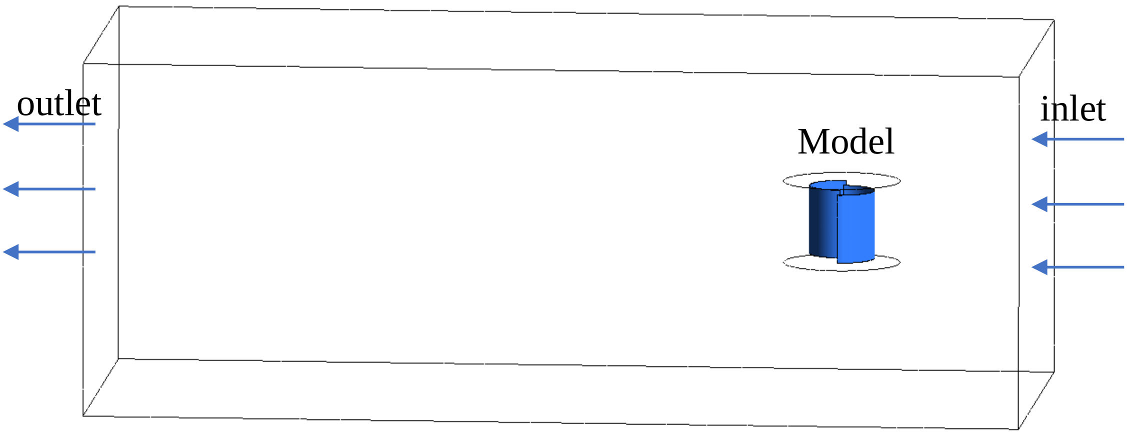
The installation of a single central turbine would provide a streamlined design and potentially simplify maintenance. Another configuration featured two turbines symmetrically positioned near the stern, allowing for balanced performance and enhanced stability during operation. Additionally, the possibility of deploying multiple smaller turbine units along the deck railing was considered, which could offer flexibility in energy generation and optimize the space utilization in the vessel. Each of these configurations presents unique advantages and challenges, warranting a thorough analysis to identify the optimal solution for the intended application.

A 2-blade Savonius turbine with height (h) = 2.0 m and diameter (D) = 1.2 m was modeled using CAD software.

- Material: Aluminum frame with composite blades.
- Rotor speed range: 20–120 RPM.
- Expected wind speed: 3–8 m/s.
- Output target: 500–1000 W per turbine.



(a) Top view (b) Side view



3. Simulation and Performance Analysis

Using computational fluid dynamics (CFD), the turbine was simulated in ANSYS-CFX with varying wind speeds and ship velocities (to simulate apparent wind changes). Turbulence was modeled using the SST k–ω model. The performance coefficients (Cp) and torque values were extracted for different conditions.

The Reynolds-averaged Navier–Stokes (RANS) technique was created and utilized in the CFD model. Incompressible flow equations created by ANSYS-CFX software were used to address flow issues in the ship walls. For incompressible flows, the averaged continuity and momentum equations are provided by the following Openwo Equations Partialger & Perić, 2002). Eqs. (1) and (2), the mass and moment equations are expressed as follows

(1) $\frac{\partial \rho}{\partial t} + \nabla.(\rho U) = 0$

(2) $\frac{\partial (\rho U)}{\partial t} + \nabla.(\rho U \; x \; U) = -\nabla p + \nabla.\tau + S_M$

where the stress tensor τ is related to the strain rate.

Furthermore, Reynolds Averaged Navier-Stokes (RANS) was developed, which is a variation of the unstable Navier-Stokes that incorporates averaged and fluctuating parameters. Anderson (Anderson, 1995) [1] Defined a turbulence model based on the RANS equation as a statistical turbulence model produced by the statistical average method used to derive the equations. The average RANS equations are provided in Equations (3) and (4)

(3) $CapCapPartial \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_j) = 0$

(4) $\frac{\partial (\rho U)}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_i U_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}(\tau_{ij} - \overline{\rho u_i u_j}) + S_M$

where τ is the stress tensor, molecular consisting of normal and shear stress components

The near-wall performance of the k ω appealing model may be employed without the possibility of causing inconsistencies to its free stream sensitivity, and it provides highly precise predictions of the start and magnitude of flow separation under undesirable pressure gradients (Menter, 1994) [10]. The SST model has benefited greatly from the strength of the fundamental turbulence model, which is why the development of an accurate and dependable near-wall formulation of the Wilcox model has greatly aided its industrial application of turbulence, heat, and mass transport. (Menter *et al*., 2003) [11].

4. Onboard Load Analysis

The electricity consumption of a vessel designed to accommodate 200 passengers is thoroughly assessed by focusing on several key operational areas. This audit encompassed various systems essential for the vessel's functionality, including lighting, which provides visibility and ambiance; air conditioning, which is crucial for maintaining a comfortable environment; navigation systems that ensure safe travel; and refrigeration units necessary for food preservation. Additionally, the evaluation considered the energy demands of crew and passenger services, such as charging stations for electronic devices and entertainment systems that enhance the onboard experience.

The analysis revealed that the average daily energy consumption of the vessel typically ranges between 100 and 150 kilowatt-hours (kWh). This range reflects the cumulative energy requirements of the aforementioned systems and services and highlights the importance of efficient energy management in maritime operations. Understanding these consumption patterns is vital for optimizing energy use, reducing operational costs, and minimizing the environmental impact of vessel operations.

Results and Discussion

1. Wind Resource in Maluku Waters

Data analysis revealed that the average annual wind speeds varied between 3.2 and 5.8 meters per second, with notable increases observed during the transitional monsoon periods of April to May and October to November. These elevated wind speeds are particularly significant, as they fall within the optimal operational range for Savonius turbines. The performance of these turbines is enhanced under conditions where the apparent wind, defined as the combination of the true wind and the speed of the vessel, plays a crucial role. This interaction between the vessel's motion and wind can lead to improved energy capture, making it an advantageous scenario for harnessing wind energy.

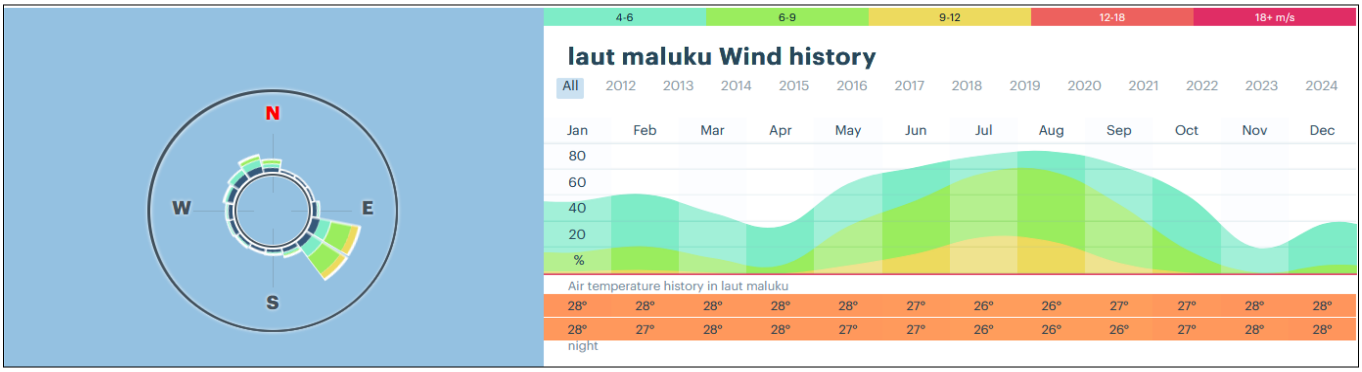


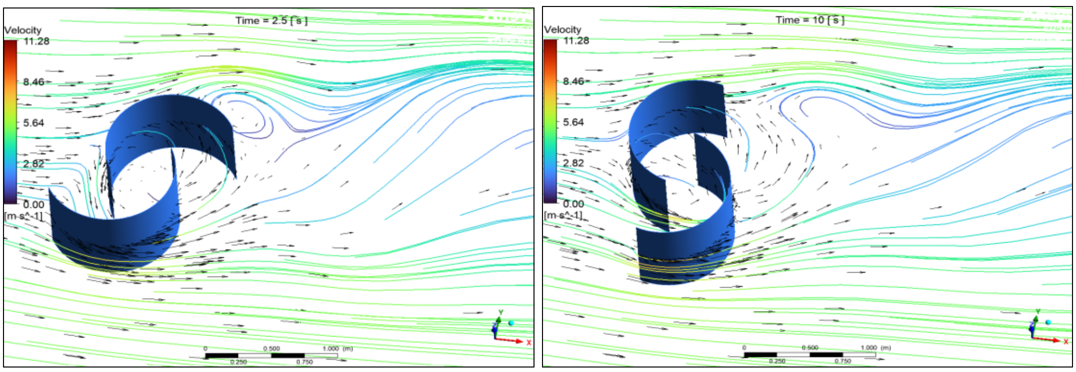
Fig 1: Monthly average wind speed on selected routes at the Maluku Sea

Furthermore, the findings underscore the importance of understanding local wind patterns and their seasonal variations, particularly for the deployment of wind energy technologies. The transitional monsoon seasons not only provide higher wind speeds but also create favorable conditions for the effective functioning of Savonius turbines. By capitalizing on these periods of increased wind activity, it is possible to optimize energy production and enhance the overall efficiency of wind energy systems. This analysis highlights the potential of integrating wind energy solutions in maritime environments, where the dynamics of wind and vessel movement can be strategically leveraged for sustainable energy generation.

2. CFD Simulation Results

CFD simulations revealed that the maximum power coefficient (Cp) achieved was approximately 0.28 at a wind speed of 5.5 m/s. This value indicates a relatively efficient conversion of wind energy into mechanical energy, suggesting that the turbine design is well optimized for performance under these specific conditions. The significance of this finding lies in its implications for energy generation, as a higher power coefficient typically correlates with an increased energy output, making it a critical factor in the assessment of turbine efficiency.

In addition to the power coefficient, the simulations demonstrated that the torque output generated by the turbine was adequate to drive a 1 kW generator at a rotational speed of 60 RPM. This capability is essential for practical applications because it confirms that the turbine can effectively produce sufficient mechanical energy to satisfy the demands of a standard generator. The ability to maintain this output at a consistent RPM is crucial for ensuring stable energy production, which is a key requirement for integrating renewable energy sources into existing power systems.



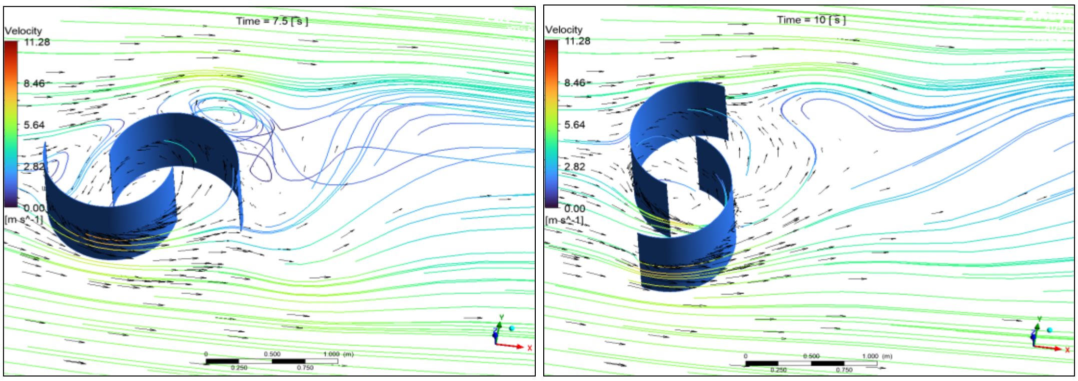


Fig2: Velocity vectors and turbulence contour for the turbine at 6 m/s.

Furthermore, the analysis indicated that turbulent airflow over the ship's superstructures had a minimal effect on the turbine performance when it was positioned above the main deck. This finding is particularly relevant for maritime applications, where the placement of turbines can be influenced by various structural elements. The negligible impact of turbulence suggests that the turbine design can be effectively utilized in such environments without significant losses in efficiency, thereby enhancing the feasibility of deploying wind energy solutions on vessels.

In scenarios involving motion, the speed of the ship, such as 8 knots, plays a significant role in enhancing the effective wind speed experienced on the windward side. This increase in speed results in a notable elevation of the wind speed by approximately 1.5 to 2.0 meters per second. Such an enhancement is crucial, as it directly contributes to the overall performance of the vessel, allowing it to harness the wind more effectively for propulsion and maneuverability.

The relationship between the ship's speed and the effective wind speed is a critical factor in maritime navigation and performance optimization. As the vessel moves through the water, the interaction between its forward motion and ambient wind conditions creates a dynamic environment that can be leveraged to improve the sailing efficiency. The augmented wind speed not only aids in propulsion but also enhances the ship's ability to maintain course and stability, particularly in challenging weather conditions.

3. Electrical Contribution Analysis

A dual-turbine setup consisting of two turbines, each rated at 1 kW, has the potential to generate a substantial amount of energy under varying wind conditions. On average wind days, this configuration can produce 4–6 kilowatt-hours (kWh) per day, which provides a reliable source of renewable energy for the vessel. This output is particularly significant as it contributes to the overall energy efficiency of the ship, allowing for a more sustainable operation while at sea.

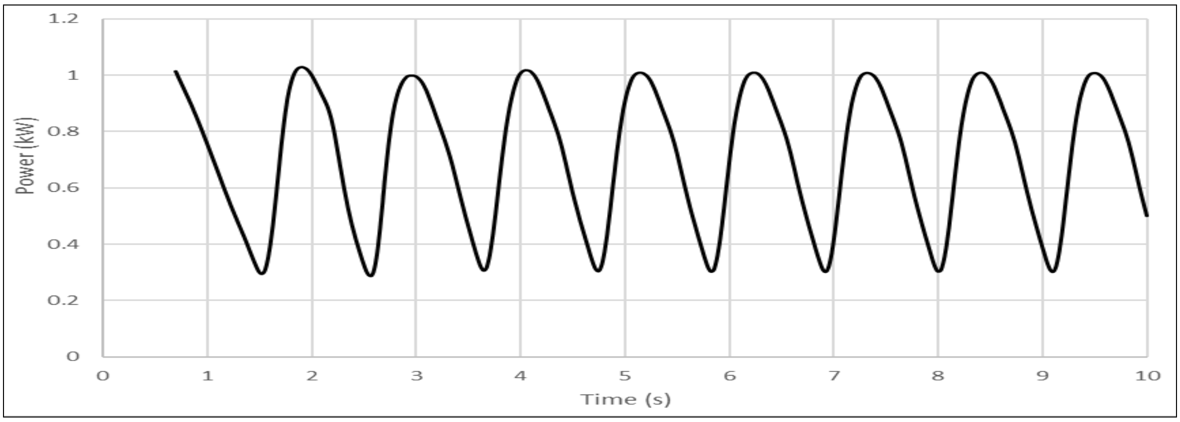


Fig 3: Power Generation

Under optimal conditions, the energy yield can reach as high as 10 kWh per day, showcasing the system's capability to harness wind energy effectively during peak performance periods. Such variability in energy production is crucial for maritime operations because it allows flexibility in energy management. The ability to generate this amount of power not only enhances the ship's energy independence but also supports the integration of renewable energy sources into its operational framework.

The energy generated from this dual-turbine configuration accounts for approximately 5–7 percent of the ship's total electrical requirements. This percentage is sufficiently significant to meet the energy demands of essential systems, such as lighting and communication equipment, thereby reducing reliance on auxiliary engines. By decreasing the runtime of these engines, ships can lower fuel consumption and emissions, contributing to a more environmentally friendly maritime industry. Overall, the implementation of such a wind energy system represents a forward-thinking approach for enhancing energy efficiency and sustainability in marine operations.

Conclusion

The integration of Savonius wind turbines into passenger vessels operating in Maluku waters presents a technically feasible and environmentally beneficial solution for partial energy support. Key findings include:

- **Wind Availability:** Maluku offers wind conditions suitable for low-speed wind turbines, enhanced by vessel motion.
- **Technical Performance:** Savonius turbines, although less efficient than horizontal-axis turbines, are well-suited for marine applications owing to their omnidirectional operation and structural simplicity.
- **Energy Contribution:** While the system contributes only 5–10% of the daily electrical needs, it helps reduce auxiliary engine use and improves sustainability.

Future work should explore hybrid configurations that combine wind and solar energy, battery storage optimization, and long-term monitoring of operational systems on passenger vessels.

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