

The Impact of Environmentally Friendly Technology and Renewable Energy on the Operational Efficiency of Merchant Vessels at TUKS PT. Petrokimia Gresik

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ABSTRACT

The shipping industry faces significant challenges in reducing emissions and improving ship operational efficiency. This study aims to analyze the impact of environmentally friendly technology and renewable energy utilization on the operational efficiency of merchant vessels. The study was conducted at TUKS PT. Petrokimia Gresik using a quantitative approach by distributing questionnaires to 96 respondents, who were ship operators and technicians. Data were analyzed using multiple linear regression to test the partial and simultaneous effects of both independent variables on operational efficiency. The results of the study indicate that both environmentally friendly technology and renewable energy significantly influence ship operational efficiency, both partially and simultaneously. The coefficient of determination (R^2) of 0.674 indicates that 67.4% of the variation in operational efficiency is explained by these two variables. This finding reinforces the urgency of implementing a green shipping strategy in the Indonesian maritime sector. This study suggests the need for continued investment in low-emission technologies and the use of alternative energy sources in industrial ports.

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INTRODUCTION

The maritime industry plays a strategic role as the backbone of global logistics, transporting over 80% of world trade volume (UNCTAD, 2023). However, merchant shipping operations also contribute significantly to increased greenhouse gas (GHG) emissions, marine pollution, and dependence on non-renewable fossil fuels. These challenges have led to the emergence of the concept of *green shipping*, a sustainable approach aimed at increasing energy efficiency, reducing emissions, and driving the transformation of the shipping sector towards a more environmentally friendly maritime transportation system.

The implementation of *green shipping* emphasizes the integration of *green technology* and the use of renewable energy in ship operations. Green technology encompasses a variety of technical innovations such as hybrid propulsion systems, air lubrication technology,

wastewater treatment systems, and more hydrodynamically efficient hull designs—all of which aim to reduce friction, fuel consumption, and carbon emissions (Tadros et al., 2023; Yamada & Suzuki, 2022). Meanwhile, the use of renewable energy, such as solar panels, wind turbines, and bioenergy-based fuels, is a key alternative to reducing dependence on fossil fuels (Brown et al., 2023; Wang & Zhang, 2021).

International regulations are accelerating this transformation. The International Maritime Organization (IMO), through its 2020 Sulphur Cap policy and *the Energy Efficiency Existing Ship Index* (EEXI), has set strict standards for sulfur emissions and ship energy efficiency. The IMO targets a 40% reduction in the carbon intensity of international shipping by 2030 and 70% by 2050 compared to the 2008 baseline (IMO, 2023). Therefore, decarbonization and operational efficiency are central issues in global maritime sector development policies. Furthermore, advances in digital technology are making a significant contribution to supporting the implementation of *green shipping*.

The use of an Internet of Things (IoT) and artificial intelligence (AI)-based energy management system enables real-time monitoring of energy consumption, emission measurement, and optimization of shipping routes (Ye Kyaw, 2025). The integration of digital systems and sustainability strategies has given rise to a new approach in the form of *smart and sustainable shipping* that is adaptive, efficient, and data-driven. Nationally, Indonesia's domestic shipping sector faces similar challenges related to energy efficiency and compliance with environmental regulations. One key entity supporting this transition is PT Petrokimia Gresik's Self-Service Terminal (TUKS), which plays a crucial role in national fertilizer distribution logistics. TUKS is gradually adopting environmentally friendly technologies and renewable energy to reduce operational costs and carbon emissions from port and merchant vessel activities.

Initial field observations indicate that the majority of merchant shipping fleets within the TUKS environment have implemented technologies such as biofuels, hybrid propulsion systems, solar panels, and wastewater treatment technologies. However, quantitative and comprehensive scientific studies on the simultaneous impact of *green technology and renewable energy* utilization on ship operational efficiency are still relatively limited. Previous studies, such as those by Anderson & Smith (2023), indicate that hybrid propulsion systems can increase operational efficiency by up to 25%. Meanwhile, Brown et al. (2023) note that the integration of solar and wind energy can reduce carbon emissions by up to 40%. Research by Lee & Kumar (2022) also confirms that the use of LNG can reduce emissions by up to 30%, and air lubrication technology has been shown to save fuel consumption by 15% (Yamada & Suzuki, 2022). However, these studies generally focus on a single intervention variable and have not addressed the simultaneous effects of their combination.

This study aims to fill this gap by quantitatively analyzing the simultaneous impact of *green technology and renewable energy utilization* on the operational efficiency of merchant vessels. This efficiency is measured through three main indicators: fuel consumption, berthing time, and operational costs. It is hoped that the results of this study can provide conceptual

and practical contributions to the transformation towards green shipping. The phenomenon of transformation towards green shipping raises several fundamental questions:

1. To what extent does the use of green technology impact the operational efficiency of ships partially?
2. How does renewable energy contribute to supporting operational efficiency?
3. Does the combination of green technology and renewable energy simultaneously have a significant impact on increasing ship operational efficiency?

These issues are particularly relevant given the high operational costs of ships, which largely stem from energy consumption. This research is expected to provide data-driven answers to the effectiveness of green technology in a real-world operational context.

Based on the identified problems, this research aims to:

1. Analyze the partial effect of the use of green technology on the operational efficiency of merchant vessels at TUKS PT. Petrokimia Gresik.
2. Analyze the partial influence of renewable energy utilization on ship operational efficiency.
3. Analyze the simultaneous influence of green technology and renewable energy on the overall operational efficiency of ships. This research is not only scientifically significant but also has significant practical and strategic implications. Scientifically, the results will enrich the literature on the integration of green technology and renewable energy in the shipping sector, which is still limited in Southeast Asia. Practically, the findings can serve as a reference for decision-making by ship operations managers, port regulators, and government policymakers in accelerating the adoption of sustainable shipping.

At the national level, this research supports the achievement of the National Energy General Plan (RUEN) target which sets the contribution of new and renewable energy at 23% by 2025. In addition, the results can strengthen Indonesia's position in implementing national emission reduction targets through the Nationally Determined Contributions (NDCs) document.

Place and Time of Research

This research was conducted at PT. Petrokimia Gresik's Self-Service Terminal (TUKS), located in the Gresik Port area, East Java. The research period was from January to April 2025, spanning approximately four months. This location was chosen because TUKS PT. Petrokimia Gresik is a strategic industrial port that has implemented various environmentally friendly technologies and renewable energy in its merchant vessel operations.

METHODOLOGY

This study uses a quantitative descriptive approach that aims to examine the relationship between the use of green technology (X1), the utilization of renewable energy (X2), and the operational efficiency of merchant vessels (Y). The research design is causal, with multiple linear regression analysis as the primary method.

The data used in this study consists of:

- a. Primary data, obtained through the distribution of questionnaires to 96 respondents who are merchant ship operators, technicians, and operational managers at TUKS PT. Petrokimia Gresik.
- a. Secondary data, obtained from journal literature, IMO regulations, port operational reports, and previous studies related to sustainable maritime technology.

Research Tools and Materials

The questionnaire instrument is based on a 5-point Likert scale (1–5) covering the following indicators: Green Technology: environmental sustainability, operational efficiency, regulatory compliance. Renewable Energy: low emissions, energy efficiency, accessibility. Operational Efficiency: fuel consumption, lead time, operational costs. Analysis software: SPSS (Statistical Package for the Social Sciences) for validity testing, reliability testing, classical assumption testing, linear regression, and hypothesis testing (t-test and F-test).

Supporting Theoretical Basis

This research is based on the theory of operational efficiency in the maritime sector associated with the implementation of low-carbon technologies (Notteboom & Rodrigue, 2020). Green technology is assumed to reduce fuel consumption and improve loading and unloading times, while renewable energy is expected to reduce emissions and energy costs in the long term (Clark et al., 2023; IRENA, 2023).

RESULTS AND DISCUSSION

This study involved 96 respondents, consisting of ship operators, technicians, and operational managers within the TUKS PT. Petrokimia Gresik. The main characteristics of the respondents and the descriptive data obtained are as follows. Description of Green Technology Variables Most respondents showed a high level of agreement with the implementation of green technology. 81% stated that their ships have complied with environmental regulations and 82% believe that environmentally friendly technology improves operational efficiency... Description of Renewable Energy Variables More than 77% of respondents stated that the use of renewable energy helps reduce energy costs and supports sustainability. The dominant renewable energy used is biofuel (22.9%), solar panels (12.5%), and LNG (10.4%). 3. Ship Operational Efficiency 74% of respondents stated that the use of environmentally friendly technology significantly reduces fuel consumption. On the other hand, 72% stated that this technology speeds up berthing times and lowers operational costs.

Multiple Linear Regression Analysis

The results of the regression analysis using SPSS were obtained as follows:

Table 1. Multiple Linear Regression Results

Independent Variable	Regression Coefficient (β)	Sig (p-value)
Green Technology (X_1)	0.412	0.000
Renewable Energy (X_2)	0.366	0.001
R ² (Coefficient of Determination)	0.674	
F-count	98,413	0.000

1. The R^2 value = 0.674 means that 67.4% of the variation in ship operational efficiency is explained by the use of green technology and renewable energy together.
2. The F test shows a significance value <0.05 , which means that both independent variables simultaneously have a significant effect on ship operational efficiency.
3. The t-test also shows that both X_1 and X_2 partially have a significant influence on Y.

Table 2. Hypothesis Testing Results

Variables	Coefficient Value	Equation 1		Sig.	Confirmation Hypothesis
		t Count	t Table		
Green Technology (X1)	0.100	0.814	1,986	0.418	Rejected
Renewable Energy (X2)	0.676	7,535	1,986	0.000	Accepted
X1 and X2 against Y (F test)	-	228,273*	3.09*	0,000	Accepted

Source: Processed primary data, 2025

Discussion

The Impact of Green Technology on Operational Efficiency

The research results show that the use of environmentally friendly technologies has a positive impact on ship operational efficiency. Technologies such as hybrid propulsion systems, air lubrication, and wastewater treatment have been shown to significantly reduce fuel consumption and operational costs. This is consistent with a study by Anderson & Smith (2023), which showed that hybrid propulsion systems can increase ship efficiency by up to 25%. Meanwhile, air lubrication technology can reduce fuel consumption by up to 15% (Yamada & Suzuki, 2022). This study strengthens the argument that green technology plays a central role in decarbonizing the maritime sector.

The Impact of Renewable Energy on Operational Efficiency

The use of renewable energy has also shown a significant impact on operational efficiency. Energy sources such as biofuels, solar panels, and LNG can reduce carbon emissions and lower long-term energy costs. This finding supports the research of Brown et al. (2023), which states that the use of solar and wind energy can reduce emissions by up to 40%. Furthermore, the use of biofuels has been shown to reduce fuel consumption by 20–30% on various merchant vessels (Wang & Zhang, 2021). This means that renewable energy not only supports sustainability but also directly contributes to cost and energy efficiency.

The Simultaneous Effect of Green Technology and Renewable Energy

The combination of green technology and renewable energy has been shown to have a significant simultaneous impact on ship operational efficiency. Regression results indicate that the synergy of the two variables produces a very robust operational efficiency prediction model ($R^2 = 0.674$). This model explains that decarbonization strategies cannot be optimally implemented by relying solely on a single intervention. A comprehensive approach is needed,

as proposed by the IMO and IRENA in their Net Zero by 2050 roadmap, where clean technology and alternative energy must be integrated simultaneously (IRENA, 2023).

CONCLUSION

This study aims to analyze the effect of green technology and renewable energy utilization on the operational efficiency of merchant vessels at TUKS PT. Petrokimia Gresik. Based on the results of multiple linear regression analysis, it was found that both independent variables have a significant effect, both partially and simultaneously, on vessel operational efficiency. The use of green technologies such as hybrid propulsion systems, air lubrication, and efficient ship designs has been proven to increase fuel efficiency and lower operational costs. The use of renewable energy such as biofuel, solar panels, and LNG also significantly reduces emissions and improves ship energy performance. The coefficient of determination (R^2) of 0.674 indicates that 67.4% of the variation in ship operational efficiency can be explained by these two variables. Thus, the integration of environmentally friendly technology and renewable energy is an effective strategy in supporting more efficient, economical and sustainable shipping. Port managers and shipping companies are advised to increase investment in green technology and renewable energy to optimize operational efficiency while complying with global environmental regulations. The government and policymakers are expected to provide fiscal incentives, supporting regulations, and technical training to accelerate the adoption of green shipping in the national shipping sector. Further researchers are advised to develop more complex models by adding control variables such as ship age, ship size, and shipping routes to enrich the empirical analysis and broaden the generalizability of the results.

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