Jurnal Sains Teknologi Transportasi Maritim
Volume 6 No.2. November 2024 pp.67-76
DOI: 10.51578/j.sitektransmar.v6i2.97
e-ISSN 2722-1679 p-ISSN 2684-9135

INVESTMENT FEASIBILITY STUDY OF AN OPEN-LOOP WET SCRUBBER ON A DRY BULK CARRIER

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(***Received***: 19-09-2024; ***Reviewed:*** 19-10-2024; ***Revised:*** 16-11-2024; ***Accepted:*** 18-11-2024; ***Published:*** 29-11-2024)

ABSTRACT

With the increasing global focus on emission reduction in the maritime industry, this study evaluates the decision to implement an Open Loop Wet Scrubber system on a 50,000 DWT Bulk Carrier. The primary objectives of this research are to assess the role of scrubbers in supporting operational efficiency and compliance with MARPOL Annex VI regulations, to determine the optimal timing for scrubber installation to minimize financial risks before ship retirement and to compare the economic efficiency of using scrubbers with high sulfur fuel oil (HSFO) against using low sulfur fuel oil (LSFO) without scrubbers. Through operational simulations on coastal and ocean-going routes, the analysis identifies potential savings, calculates return on investment (ROI), and determines the break-even point (BEP). The results indicate that the installation of an Open Loop Wet Scrubber offers significant long-term savings, with the payback period varying based on route selection and fuel strategy. This research provides critical insights for shipping companies seeking to enhance their competitiveness by balancing compliance with environmental regulations and operational efficiency.

Keywords: Bulk Carrier; Decarbonization; Emission Control Area; Marine Pollution; Scrubber; Sustainability

INTRODUCTION

The maritime industry, with a particular focus on sea trade routes, plays a crucial role in the global economy. However, it is also a significant source responsible for the emission of considerable greenhouse gases (IMO, 2020a). Based on data from the International Maritime Organization (IMO) indicates that the maritime sector is responsible for approximately 2.5% of total global carbon dioxide (CO2) emissions (IMO, 2020b). Emissions from the maritime sector are nearly on par with those of the aviation industry, both contributing significantly to global CO2 emissions among hard-to-abate sectors" (Miller & Façanha, 2014; Ritchie, 2024).

The projection of a significant increase in the scale of maritime trade in the coming decades has prompted concerns about the potential for further emissions increases. IMO has issued a series of regulations through the International Convention for the Prevention of Pollution from Ships (MARPOL), one of which is Regulation 14 in Annex VI, which sets the maximum limit for sulfur content in ship fuel (IMO, 2020b). This regulation not only aims to reduce sulfur oxide (SOx) emissions, which are harmful to health and the environment but also supports global efforts to meet the target of Sustainable Development Goal (SDG) No. 13 by focusing on actions to combat climate change and reduce greenhouse gas emissions (United Nations, 2015).

In the context of sea trade, dry bulk ships play a significant role by controlling around 40% of total global sea trade (UNCTAD, 2021). At the national level, dry bulk ships in Indonesia serve more

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than 100 million tons of dry bulk cargo annually, making it the primary support for national logistics (Ministry of Transportation Indonesia, 2022). Dry bulk ships with a capacity of approximately 50,000 DWT dominate the domestic market share, with more than 200 ships contributing around 30% of the total DWT on national shipping lines (Indonesian Bureau of Statistics, 2023). Under strict MARPOL Annex VI regulations, operating ships must meet the established emission standards. Installing scrubbers is one of the leading solutions for filtering ship exhaust gas, especially to comply with Regulation 14 of MARPOL (ABS, 2020). In particular, Wet Scrubber Open Loop technology offers several advantages, such as lower operational costs and better efficiency in filtering sulfur from emissions compared to conventional scrubber technology (Letnes, 2013).

Muzhoffar et al., (2024) discussed the effectiveness of route selection in the LNG distribution scheme using the Milk-Run and Hub-Spoke methods on small-scale LNG ships in Eastern Indonesia. This study emphasizes that efficient route selection can significantly reduce operational costs and fuel consumption, which directly contributes to emission reductions. These findings are consistent with Suryadi & Sunarso (2024), which examined the readiness of shipping companies to implement IMO regulations related to marine pollution prevention. It concluded that regulatory compliance, including adopting emission reduction technologies is essential for achieving sustainability in maritime operations. Further, Setiyantara et al. (2024) highlighted the importance of optimizing loading and unloading equipment to improve operational efficiency, which can also support emission reduction efforts by reducing fuel consumption during port activities. Both studies underscore the broader need for integrated strategies in maritime logistics to comply with environmental regulations and enhance overall operational performance. This study found that the Milk-Run scheme effectively reduces operational costs and minimizes total shipping distance when sending a vessel to several destinations from one point of origin. This study identifies the principles of efficient route selection by ships equipped with Wet Scrubber Open Loop systems to manage their emissions. Dry bulk ships can reduce fuel consumption and exhaust emissions by adopting the same approach to route selection. Thus, more efficient journeys result in lower fuel use and fewer emissions. Therefore, an optimized route selection strategy can support emission reduction goals and compliance with environmental regulations while maintaining high operational efficiency.

A literature review reveals several studies have addressed various aspects of emissions and emission reduction technologies in the maritime industry. A study conducted by Endresen et al. (2003) provides insights into the environmental impacts of international sea transportation, underscoring the pressing need for emission reduction measures. Yang et al. (2021) examine the effectiveness of wet scrubber systems on container vessels and highlight their potential to reduce emissions on long-haul routes. Meanwhile, Karatuğ et al. (2022) conducted a feasibility analysis that emphasizes the economic viability of scrubber installations for shipping fleets and reveals significant long-term benefits. Issa et al. (2019) offer a broader economic perspective, comparing various emission reduction techniques applicable to marine diesel engines. However, studies that specifically discuss the application of scrubbers to dry bulk ships are still limited. This study aims to bridge this gap by examining the emission reductions and economic efficiency that a Wet Scrubber Open Loop system can achieve on a 50,000 DWT dry bulk ship. This study employs quantitative analysis to assess the return on investment (ROI) and break-even point (BEP) associated with the installation of Open Loop Wet Scrubbers. The use of quantitative analysis is justified by the need for objective, numerical evaluation of the financial performance and economic feasibility of this technology over time. ROI is selected as it provides a clear measure of profitability by comparing operational savings to the initial and maintenance costs, offering decision-makers insight into the long-term value of the investment.

The BEP method complements this by determining the minimum time required for revenues to cover the costs, which is critical in managing financial risks. Together, these methods allow for a comprehensive financial evaluation, balancing the need to comply with environmental regulations while ensuring operational efficiency and economic sustainability. This systematic approach ensures that the analysis captures both short-term liquidity and long-term profitability, providing a robust basis for investment decisions. The data that will be used includes ship operational information, scrubber installation and maintenance costs, fuel prices, and estimated emission savings based on specific shipping routes. The analysis methods that will be applied include ROI analysis to evaluate long-term financial benefits and the BEP method to determine how long it will take to reach the break-even point on this scrubber investment. This study's objective is to provide clear guidance for decision-makers in selecting the most effective strategy for compliance with emissions regulations while maintaining the economic efficiency of ship operations.

MATERIALS AND METHODS

Materials

This study identifies data as an indispensable preliminary step in mapping the operational intricacy of the system installation, Wet Scrubber, on a 50,000 DWT Bulk Carrier ship. This process aims to obtain a comprehensive understanding of critical variables, which will serve as the foundation for analyzing efficiency and return on investment. This data serves as the foundation for designing an in-depth and comprehensive analysis model. The collected includes:

1. **Scrubber Configuration and Vendor Offerings**
   In the case of a 50,000 DWT bulk carrier operated by *Shipping Management J*, the primary factor influencing investment decisions regarding the installation of a wet scrubber open loop system is cost analysis. The cost of this equipment can vary greatly, depending on the technology used and the brand of scrubber offered by each vendor. Some vendors offer comprehensive packages that include equipment and installation costs, while others provide pricing for either the equipment or the installation separately. This study considered a variety of offerings from vendors to gain a more detailed understanding of the costs involved. Vendor P offers a scrubber for 10.4 billion IDR, while Vendor Q provides a comprehensive package that includes installation costs and supplementary features for 18.5 billion IDR. Vendor R offers a scrubber for 16 billion IDR, excluding installation costs, while Vendor S provides an installation-only option for 19 billion IDR. Vendor R was excluded from this study as its offering only covered the scrubber price without installation or additional features, making it less suitable for a comprehensive comparison. Instead, Vendor P and Vendor S were combined, as Vendor P provides the scrubber at the lowest price among the options, while Vendor S specializes in installation services. By merging the offerings of these two vendors, their total package becomes comparable to Vendor Q's comprehensive solution, enabling a more balanced analysis of costs and benefits.

2. **Emission Control Area (ECA) Compliance**
   Data related to compliance with Emission ECA regulations includes fuel requirements and scrubber use on routes that pass through the ECA zone. To reduce sulfur pollution, ships operating in the ECA area must comply with stricter emissions limits. Since it was first adopted in 1997, Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) has undergone several revisions to further tighten limits on sulfur emissions from ships. The most recent significant change occurred on January 1 2020 when the global maximum limit for sulfur content in ship fuel was lowered to 0.5% m/m. Previously, this limit started at 4.5% m/m and continued to be tightened to 3.5% m/m until it reached 0.5% m/m in 2020 (IMO, 2020b). In ECA areas, such as the Baltic Sea, North Sea, North American Coast and Caribbean Sea in the United States, the maximum limit for sulfur content until 2010 was set at 1.5% m/m (IMO, 2020a). In 2010, the IMO tightened this limit to 1% m/m, further reducing it to 0.10% m/m from 1 January 2015 (IMO, 2020b). This policy emphasizes the importance of using low-sulfur fuel or suitable scrubbers to meet the stringent environmental requirements of the region.

3. **Voyage Plan Details for coastal-going and ocean-going shipping routes**
   In this study, the selected shipping routes include both coastal-going and ocean-going, with consideration given to the relevant emission regulations and the use of scrubbers to reduce sulfur

 e-ISSN 2722-1679 p-ISSN 2684-9135

emissions from ships. This route selection is based on operational needs, compliance with regulations, and operational efficiency that can be achieved through the use of scrubbers and fuel strategies.

The coastal-going shipping routes used involve traveling between TJ Pemancingan Harbor and TJ Merpati Harbor, two main ports in Indonesia that are often used by *Shipping Management J* for its operational activities. This route was chosen because it is an area that has been designated for this study following the instructions given, and is the route most frequently used for domestic shipping activities. *Shipping Management J* planned this route to encompass a 15-day shipping cycle, which includes five days of loading progress (LD), three days of shipping to the loading location (sailing loading/SL), three days of waiting for the unloading process (WU), five days of unloading (discharge/DI), and two days of ballast sailing (sailing ballast/SB) without cargo, as illustrated in Table 1.

Table 1. Coastal-going voyage plan

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sailing					SL	SL	SL							SB	SB
Notice of Readiness							WU	WU	WU						
Operation	LD	LD	LD	LD	LD				DI	DI	DI	DI	DI		

*SL: Sailing Loading; LD: Loading; WU: Waiting Unloading; DI: Unloading; SB: Sailing Ballast.

These two ports implement strict regulations regarding the use of scrubbers, both open loop, closed loop, and hybrid types, as part of efforts to comply with international standards and preserve the maritime environment. At this port, ships are required to use fuel with a sulfur content of no more than 0.5% m/m and report the type and source of fuel to the port authority. This route also requires ships to provide complete documentation regarding scrubber installation and operations and report scrubber operational data periodically to ensure compliance with applicable regulations.

The ocean-going routes managed under *Shipping Management J* consider several strategic considerations that led to the selection of the Port of Shanghai in China as the destination for ocean-going shipping routes from Indonesia. This route is the closest ocean-going shipping route to the main market in China. In addition, along this route, there are several ECA that enforce strict regulations regarding sulfur emissions from ships. Although ships are permitted to use scrubbers, the effectiveness of scrubber use in reducing sulfur emissions in this zone may be less than optimal due to additional requirements regarding fuel use. Therefore, ships sailing to ECA, including the Port of Shanghai, often have to combine high-sulfur fuel oil (HSFO) and low-sulfur fuel oil (LSFO) to meet applicable emissions requirements. This ocean-going shipping route is planned for 30 days, covering various operational stages. This stage includes five days for LD, ten days of SL, 1 day waiting for documents (Waiting Document/WD), four additional days waiting for documents at the destination port, five days for DI, and 10 days of SL without cargo returning to the port of origin, as illustrated in Table 2.

Table 2. Ocean-going voyage plan

Day	1	4	5	13	14	15	16	17	18	19	20	21	28	29	30
Sailing			SL	SL	SL							SB	SB	SB	SB
Notice of Readiness				WD	WU	WU	WU	WU							
Operation	LD	LD	LD					DI	DI	DI	DI	DI			

*SL: Sailing Loading; LD: Loading; WD: Waiting Document; WU: Waiting Unloading; DI: Unloading; SB: Sailing Ballast.

The Port of Shanghai was chosen as the primary destination for this ocean-going route due to its significant role in international trade and its 10-day shipping distance, allowing for accurate operational efficiency and cost savings calculations. The port's strict environmental policies, including using clean fuel with a sulfur content of no more than 0.1% m/m and appropriate scrubbers, also make it an ideal choice for this study. This 10-day shipping time allows for more accurate calculations of operational efficiency and cost savings.

4. **Fuel Consumption and Costs**.
It includes calculations of HSFO and LSFO fuel costs used with scrubbers, including daily consumption and fuel costs at the port. Calculating the difference in fuel prices involves comparing the costs between two or more fuel types used in ship operations. In the context of scrubber and fuel use, this calculation may involve a comparison between the costs of HSFO and LSFO, or Marine Gas Oil. Based on offers from two suppliers, Supplier A offers HSFO for IDR 11,200.00 per liter. On the other hand, Supplier B provides discounts, namely HSFO at IDR 12,040.00 per liter and LSFO at IDR 13,860.00 per liter. This comparison assesses the most cost-effective fuel for the ship's operational requirements.

Methods

In evaluating the financial feasibility of Open Loop Wet Type Scrubber investments, two primary methods are commonly utilized: the ROI and BEP. These instruments provide insight into the profitability and risk of investments. ROI assesses profitability versus costs, while BEP identifies minimum operational thresholds to achieve profitability. This approach facilitates financial analysis, assisting in strategic scrubber decisions.

ROI is a commonly used approach to evaluate the financial effectiveness of an Open Loop Wet Type Scrubber investment. This method assesses how well the profits generated from operating ships equipped with scrubbers can cover the initial investment costs. Similar approaches to evaluating scrubber investments are detailed in works by DNV GL, (2020). The ROI equation reflects the balance between operational savings (achieved through emission compliance) and investment expenses. ROI is calculated by comparing the net income from operational efficiency with the total investment costs, which include the price of the scrubber, installation, and maintenance expenses. Over the next 10 years, total revenue (r) are determined by multiplying the savings (s) per year (whether ocean-going or coastal-going) by 365 days and the number of years after the investment (t). ROI is then derived by subtracting the total investment (i) from total revenue (r) and dividing the result by the total investment (i), providing a measure of the profitability of the scrubber investment, as shown in the following equation.

$$ROI = \frac{(r-i)}{i}, \qquad r = s \times t \times 365 \tag{1}$$

Moreover, BEP is a financial tool used to determine when the revenues from operating ships equipped with scrubbers will begin to cover all incurred costs. It calculates the minimum number of operational instances required for the investment to break even. By analyzing the BEP, it is possible to estimate when an investment in a scrubber will start to generate profits, considering variables such as fuel prices, maintenance costs, and freight rates. The payback period is a financial analysis tool that helps assess the investment's liquidity and risk. The BEP is calculated by dividing the total investment (i) by the difference between the savings (s) generated from the scrubber and the additional costs associated with auxiliary engine operation and maintenance (am) and scrubber maintenance (sm). This is expressed in the equation below, which illustrates the payback period for the scrubber investment to reach its profitability.

$$BEP = \frac{i}{s-(am+sm)} \tag{2}$$

Research Procedure

This research was carried out in several stages, starting from identifying the problem and objectives to analysis of results and conclusions. The following is a flowchart of the research:

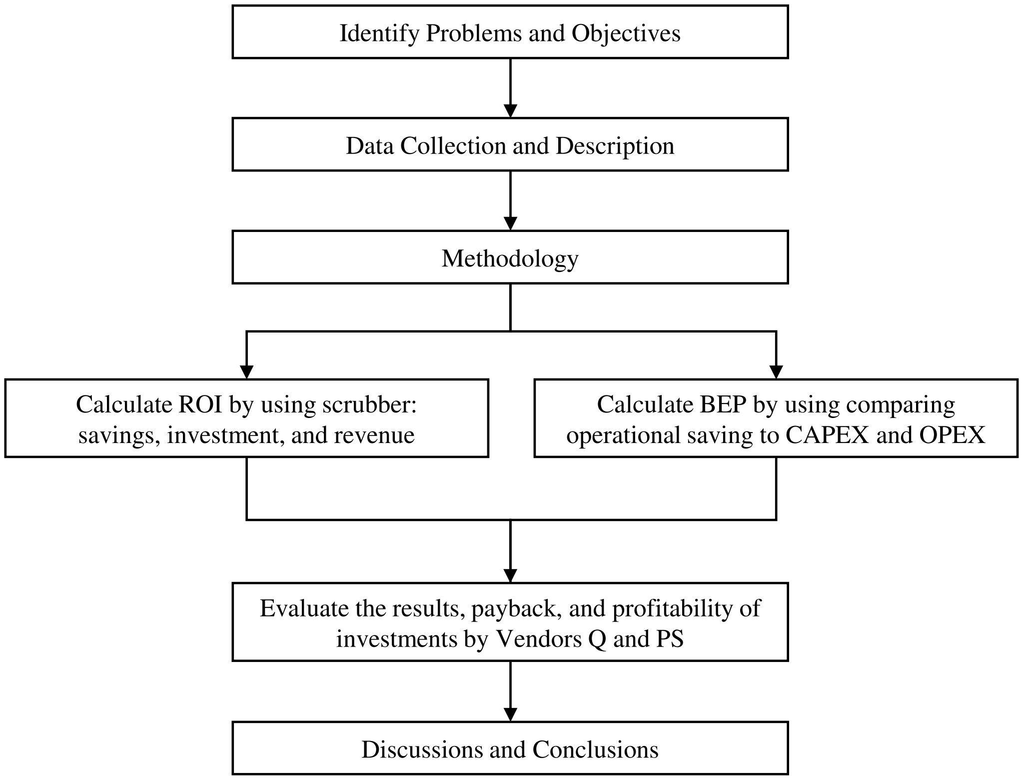

Figure 1. Research Procedure

The research flow procedure in the flowchart above starts with identifying the problem and research objectives. This is followed by collecting and analyzing data to obtain relevant information for the research. After the data is collected, a suitable methodology is selected to ensure that the approach used is appropriate in answering the research objectives. The next stage is calculating the Return on Investment (ROI) based on savings from the use of scrubbers, investment spent, and projected revenue. In addition, a Break-Even Point (BEP) calculation was also carried out by comparing operational savings to initial costs and maintenance costs.

The results of the ROI and BEP calculations were then interpreted, followed by an evaluation of the payback period and investment profitability of the two vendors under review, namely Vendors Q and PS. After the evaluation, a performance comparison between vendors was conducted to determine which was superior in profitability and efficiency. The final stage of the research process is to analyze the findings of the entire study and draw conclusions that address the initial objectives and problems identified at the outset of the research project.

RESULTS AND DISCUSSIONS

Return on Investment (ROI)

ROI analysis applied to the collected data or variables is expected to provide an overview of how investment in scrubber technology will develop from 2025 to 2034. Each vendor has generated a complete description of the ROI growth based on the obtained results.

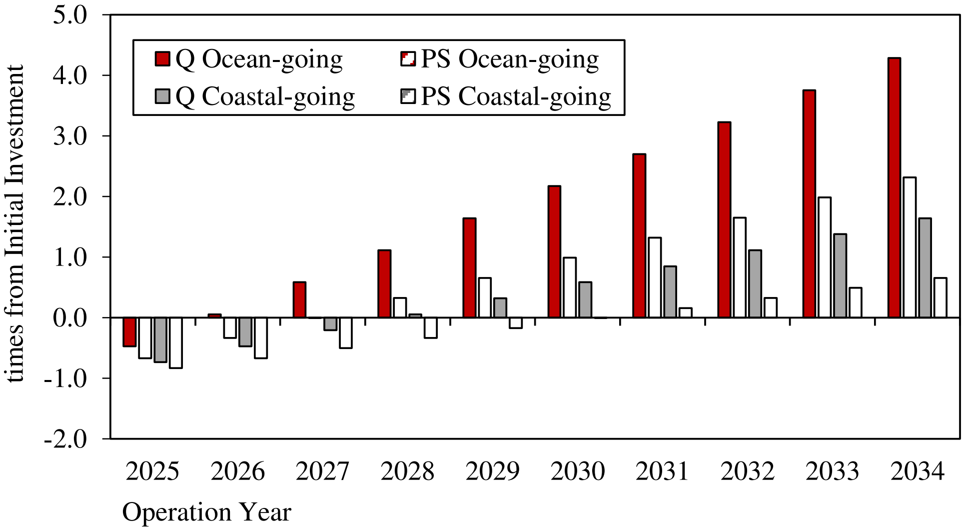

Figure 2. Return on Investment (ROI) results of Vendors Q and PS

Results in Figure 2 show the growth of ROI from the ocean-going investment by Vendor Q in the period 2025 to 2034. ROI begins to be seen in 2026 with a low value (0.0571 times the investment that has been made) after 2025, which does not show a significant ROI. However, as time passes, ROI increases consistently until it reaches its highest value at 4.2854 times the investment made in 2034. A period of significant growth begins in 2028 when ROI exceeds 1.1141 and continues to increase every year, showing that these investments become increasingly profitable over time. Figure 1 demonstrates that Vendor PS's ocean-going investment yielded a negative ROI from 2025 to 2027. However, it gradually increased from 2028 to 2034, reaching a peak of 2.3157 times the initial investments. Compared to previous data from Vendor Q, Vendor PS's ROI took longer to achieve significant growth. While Vendor Q shows a steady positive ROI starting in 2026 with faster growth and the highest ROI of 4.2854 times the investment already made in 2034, Vendor PS investments will take until 2030 to start seeing substantial returns, with ROI reaching 2.3157 times the investment made in the last year of analysis. This shows that Vendor Q achieved a higher and faster return on investment compared to Vendor PS.

For coastal-going operations, this investment experienced a decline in value in the first three years (2025 to 2027), as indicated by a decreasing negative ROI. However, starting in 2028, ROI shows a continuous positive increase, with each year recording significant growth until it reaches its highest value in 2034 with a value of 1.64. Compared to Vendor Q's ocean-going ROI, which showed earlier stability over the same period, Vendor Q's coastal-going ROI took longer to recover and start delivering profits. These results show that although initially the investment in Vendor Q resulted in losses, in the long term the investment provided significant returns and showed consistent improvement from year to year. Figure 1 also shows that this investment experienced losses in the first five years (2025 to 2030) with a negative ROI value that gradually decreased, indicating initial difficulties in obtaining positive returns. However, ROI began to show a positive increase in 2031, which continued until it reached its highest value in 2034 with a value of 0.6579. Compared to Vendor PS's ocean-going ROI, which showed more consistent positive growth since the start of the period, Vendor PS's coastal-going ROI demonstrated a slower recovery and only started to register positive results after the first five years. This indicates that investment in ocean-going vendor PS reaches a point of stability faster than in coastal-going vendor PS.

Break Even Point (BEP)

BEP analysis in maritime sector investment aims to provide a clear picture of the duration required for income to cover costs. Understanding BEP on coastal-going and ocean-going routes is important to assess investment efficiency and the speed at which a company can reach the break-even point. By analyzing BEP, companies can better understand existing risks and potential and make more appropriate strategic decisions. Based on the obtained results, each vendor generates a complete picture of the ROI growth. Further, Figure 3 presents the results of the analysis, indicating the time required to achieve BEP in ocean-going and coastal-going operations for two different scrubber vendors.

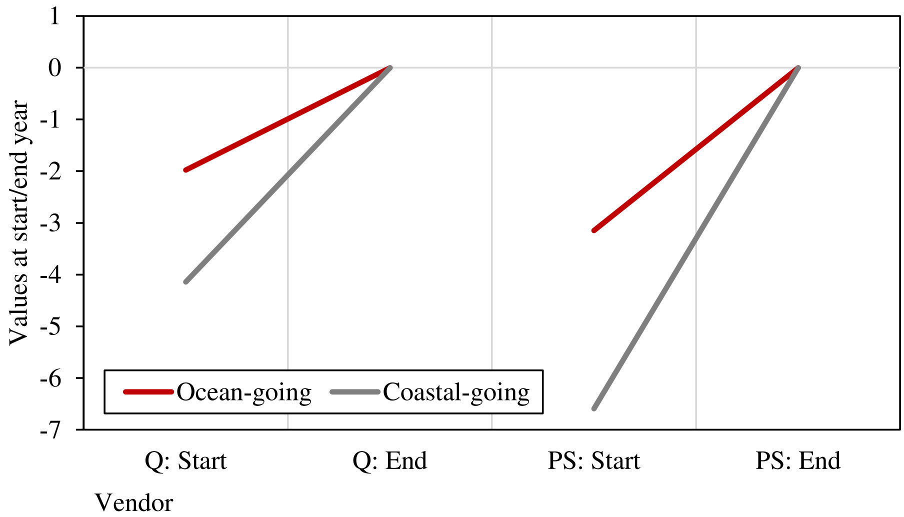

Figure 3. Break Even Point (BEP) results of Vendors Q and PS

The analysis shows that ocean-going operations reach BEP almost twice as quickly as coastal-going operations, taking 721 days (1.98 years) for ocean-going and 1,510 days (4.14 years) for coastal-going. Vendor Q is more efficient than Vendor PS, which takes longer to reach BEP. In ocean-going operations, Vendor PS requires 1,150 days (3.15 years) compared to Vendor Q. This difference is more striking in coastal-going operations, where Vendor PS requires 2,407 days (6.59 years), which is much longer than Vendor Q. This data confirms that Vendor Q has superior time efficiency to achieve BEP in both types of operations. Time efficiency in achieving BEP is important because it directly impacts saving operational costs and increasing economic efficiency for maritime companies. Therefore, selecting the right scrubber vendor, such as Vendor Q, can provide benefits in terms of costs and time to break even.

Discussions

Based on the results of ROI and BEP calculations that have been carried out, this research provides insight into investment options that are more profitable in using scrubbers on ships. The analysis shows that investing in Vendor Q is more profitable than Vendor PS because of the faster payback period of between two to four years and the potential for greater profits after breaking even. This reflects that vendor Q offers a more efficient and economical solution, especially when payback time is an important factor in making investment decisions. On the other hand, investing in PS vendors requires a longer payback period with smaller profit potential, so this choice is less than optimal if time efficiency and cost control are priorities. This study suggests that future research should focus on developing investment strategies that consider fuel market conditions, scrubber price variations, and ship operational scenarios to increase the effectiveness of future investment decisions.

This study can be developed further to evaluate the environmental impacts of using various types of scrubbers and fuels, especially in the long term. This approach is important for understanding how technology and fuel choices affect emissions and ocean quality over time. Additionally, future research could investigate the risks associated with fuel price fluctuations, scrubber maintenance costs, and the risks of using low-carbon fuels. For instance, Hosseini et al. (2023) explore the possibility of utilizing a blend of diesel and hydrogen fuels to lower carbon emissions and enhance ship engine performance. This study shows that this fuel mixture effectively reduces emissions while increasing engine efficiency.

However, using hydrogen as a ship fuel carries significant environmental risks, including the potential for fire and explosion, which requires careful management. These risks emphasize the need for more careful planning and risk management in using hydrogen fuel to ensure operational safety. For example, additional safety measures such as hydrogen leak detection systems increased ventilation in engine areas, and crew training on emergency protocols are essential to minimize this potential risk. By considering these factors, companies can develop more comprehensive investment policies that focus not only on cost efficiency but also on operational sustainability and environmental responsibility. These findings are also relevant in the regulatory context of MARPOL Annex VI increasingly stringent regulations requiring ships to reduce sulfur and greenhouse gas emissions. The utilization of hydrogen-blended fuel by shipping companies not only enables compliance with the relevant regulations but also facilitates enhanced operational efficiency and the reduction of long-term costs. This discussion emphasizes the importance of a holistic investment approach, where technology selection and operational strategies must be based on analysis that considers long-term savings potential, environmental impact, and compliance with international regulations. Future research can be focused on developing more sophisticated simulation models to predict investment outcomes under various market conditions and regulatory changes. This model will help companies evaluate different investment scenarios, from fluctuating market conditions to implementing stricter environmental regulations, thereby supporting more adaptive and sustainable investment strategies.

CONCLUSION

This study evaluates the economic effectiveness of installing a Wet Scrubber Open Loop system on a dry bulk ship with a capacity of 50,000 DWT to comply with MARPOL Annex VI regulations regarding sulfur content limits in fuel. The ROI and BEP analyses show that investment in scrubber technology provides significant returns over a certain period. Vendor Q has been proven to be more efficient in terms of payback time than the Vendor PS combination. Installing these scrubbers can reduce operational costs and increase compliance with environmental regulations, thereby strengthening the competitiveness of shipping companies. Selecting a scrubber vendor that is efficient in terms of cost and time to attain BEP is crucial in making investment decisions.

The study recommends further research to explore the environmental impacts of scrubber use and broader investment scenarios, considering variations in fuel prices, maintenance costs, and increasingly stringent environmental regulations. Future research should also incorporate an examination of the effects of implementing environmentally friendly technology and using new and renewable fuels on crew safety and the environment, with a comprehensive analysis of potential fire and explosion hazards associated with these advanced technologies and fuels. Future research plans should incorporate studies on the effects of implementing environmentally friendly technology and using new and renewable fuels on crew safety and the environment. This encompasses an exhaustive examination of the potential fire and explosion hazards associated with the deployment of these recently developed technologies and fuels.

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