# SLOW STEAMING IMPACT ON CONTAINER SHIP'S FUEL CONSUMPTION AND CARBON EMISSION, CASE STUDY: SURABAYA-MAKASSAR ROUTE

**Haikal Anjasmara[1], Muhammad Dhaifullah[1], Lista Putri Adinda Rahmi[1]**

[1] Department of Naval Architecture, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
E-mail: haikal.anjasmara98@gmail.com

**Received:** December 15, 2023 | **Accepted:** April 22, 2024 | **Published:** April 22, 2024
**DOI:** 10.12962/j27745449.v5i2.1009 | **Issue:** Volume 5 Number 2 2024 | **E-ISSN:** 2774-5449

## ABSTRACT

This research investigates the implementation and environmental impact of "slow steaming" as an innovative method in maritime transportation, focusing on the route from Surabaya to Ambon. Utilizing a container ship model with a capacity of 100 TEUs, the study examines resistance data, engine power requirements, and the selection of a main engine aligned with sustainability goals. Slow steaming's influence on fuel consumption and emissions is analyzed, emphasizing cost-effectiveness and environmental benefits. The study extends to sailing route calculations, highlighting reduced oil consumption during slow steaming. Additionally, the research calculates the Energy Efficiency Existing Ship Index (EEXI), crucial for assessing and improving energy efficiency in compliance with International Maritime Organization regulations. The analysis of the container ship scenarios reveals optimal operational conditions and financial performance. In the Round-trip Full Load scenario, peak profitability is achieved at 77% engine load (10.5 knots), yielding Rp50,376,332,800.00 profit. In the Round-trip 1.5 Load scenario, maximum profit occurs at 54% engine load (9.5 knots), resulting in Rp21,245,220,000.00 profit. Bunkering costs, constituting 30-50% of the total cost, significantly influence economic dynamics. The Energy Efficiency Existing Ship Index (EEXI) peaks at 11 knots (31,166.06552) and reaches a minimum at 9.5 knots (22,518.17557). These insights offer guidance for optimizing maritime operational parameters and financial outcomes.

**Keyword:** Slow Steaming, Fuel Consumption, Emission.

## Introduction

Adoption of innovative methods is critical in the quest for a more sustainable maritime industry. One such tactic that is gaining traction is "slow steaming," a practice that goes beyond typical shipping norms by focusing on fuel efficiency and emission reduction. This paradigm shift is most noticeable on the marine route from Surabaya to Ambon, where the adoption of slow steaming not only improves operational cost-effectiveness but also greatly contributes to environmental stewardship.

The route from Surabaya to Ambon, which spans Indonesia's gorgeous archipelago, has historically served as a crucial maritime corridor connecting major trading hubs. Recognizing the environmental impact of traditional shipping techniques, there is an increasing push to implement sustainable alternatives. Slow steaming emerges as a beacon of change, altering how ships navigate these seas.

Slow steaming, at its core, entails operating vessels at speeds lower than their full capabilities, consciously selecting a controlled pace to maximize fuel use. This deliberate reduction in speed not only saves fuel but also results in a significant reduction in greenhouse gas emissions. Slow steaming offers a tangible and positive move towards a more ecologically conscious maritime industry as ships ply the waters between Surabaya and Ambon.

As we embark on this journey from Surabaya to Ambon, slow steaming stands as a testament to the maritime industry's commitment to a greener future. The deliberate pace at which vessels traverse these waters is symbolic of a paradigm shift—one that prioritizes sustainability without compromising efficiency. With every nautical mile covered, the Surabaya to Ambon route becomes a living example of how embracing innovation can propel the maritime industry towards a more environmentally conscious and economically viable future. Research aims to investigate the impact of slow steaming on fuel consumption and ship emission with boundary journey destination from Surabaya to Ambon.

## Methodology

### Ship Dimensions and Route

A container ship, a specialized type of cargo vessel, is designed to transport standardized cargo containers, facilitating efficient loading, unloading, and transportation of goods. These ships have been instrumental in advancing global trade through a standardized and cost-effective approach to moving goods across international borders. The research utilized container vessels with key dimensions outlined in Table 1.

**Table 1.** Principle dimension of container

| **Ship Dimensions** | | |
|---|---|---|
| **Lpp** | 74,26 | m |
| **Lwl** | 76,06 | m |
| **B** | 17,4 | m |
| **D** | 5 | m |
| **Tf** | 3 | m |
| **Ta** | 3 | m |
| **Δ** | 2898,56 | $m^3$ |
| | 2985,84 | tonf |
| **S** | 1445,23 | $m^2$ |
| **Route** | SBY - AMB | |
| **Distance** | 1018 | Nmiles |

Tanjung Perak Port and Yos Soedarso Port are two vital maritime gateways in Indonesia, each playing a significant role in the country's economic development and regional connectivity. Tanjung Perak, located in Surabaya, is one of the busiest ports in the archipelago, serving as a crucial hub for trade and commerce. Its strategic location has historically made it a focal point for international shipping, fostering economic growth and cultural exchange. On the other hand, Yos Soedarso Port, situated in the vibrant city of Ambon, serves as a gateway to the eastern part of Indonesia. This port facilitates trade and transportation, connecting the nation's diverse islands and contributing to the economic integration of the region. Both ports not only handle the import and export of goods but also play a pivotal role in promoting Indonesia's rich maritime heritage. The juxtaposition of these two ports highlights the diverse economic activities and cultural interactions that define Indonesia's dynamic landscape. As Indonesia continues to position itself as a key player in the global economy, Tanjung Perak Port and Yos Soedarso Port stand as symbols of the nation's maritime prowess and its commitment to sustainable development.

### Ship Resistance and Powering

The fuel consumption of ships is influenced not only by the power of the main engine but also by various factors such as the type of engine (stepped and speed), engine load (load factor), type of fuel used (energy density), the year of engine manufacture, the operational duration of the ship, the fishing gear employed, engine maintenance levels, and even the operational habits of the crew. For container ships, fuel consumption varies based on factors and conditions such as vessel size, age, and condition, engine power, vessel speed, gear configuration, sea state, and weather conditions. The calculation of fuel consumption begins with determining the ship's resistance, utilizing Equation 1.

$$RT = \tfrac{1}{2}\,\rho \times C_T \times S \times V^2 \qquad (1)$$

Where RT is the total resistance, ρ is fluid density, CT is coefficient of frictional resistance, S is a wetted surface area, and V is ship velocity. Once the total resistance on the ship has been calculated, the next step is to determine the engine power required by the ship. The calculation of engine power utilizes the equation:

$$EHP = RT \times Vs \qquad (2)$$

$$BHP = SHP/0.85 \qquad (3)$$

$$SHP = DHP/0.85 \qquad (4)$$

$$DHP = EHP/QPC \qquad (5)$$

$$QPC = nh \times nrr \times np \qquad (6)$$

Where Effective Horse Power (EHP) represents the engine's power output. It is a crucial measure that indicates the actual power delivered by the engine. Brake Horse Power (BHP), on the other hand, is the power that the engine delivers to the output shaft. This measurement is essential in understanding the engine's performance and efficiency. Shaft Horse Power (SHP) is the power transferred through the shaft, providing insights into the power distribution within the mechanical system. Delivery Horse Power (DHP) signifies the power available for performing useful work, reflecting the engine's ability to contribute to practical applications. Lastly, Propulsive

Coefficient (QPC) is a parameter that expresses the ratio of effective thrust power to the delivered power, offering a quantitative understanding of the propulsion system's efficiency. Each of these terms plays a distinct role in assessing and comprehending the various aspects of an engine's power and performance.

### Energy Efficiency Existing Ship Index (EEXI)

The Existing Vessel Energy Efficiency Index (EEXI) serves as a key metric in assess and improve the energy efficiency of existing ships, contributing to the goal International Maritime Organization (IMO) to reduce greenhouse gas emissions from maritime sector. The EEXI calculation involves the following systematic process.

Apply correction factors to the baseline, taking into account technical characteristics such as main engine power, deadweight of the vessel, and design speed. These factors adjust the baseline to accommodate the unique features of the ship.

Calculate the Energy Efficiency Design Index (EEDI) for the vessel based on its design parameters. This foundation represents the energy efficiency level that the ship should meet during its initial design and serves as a crucial input for subsequent EEXI calculations.

Establish the actual EEXI by comparing it to the prescribed EEXI. The prescribed EEXI is calculated from the baseline adjusted with correction factors, presented as a percentage of the EEDI baseline.

Evaluate compliance by comparing the achieved EEXI with the required EEXI. If the achieved EEXI is equal to or less than the required EEXI, the vessel is considered compliant. Exceeding the required EEXI may necessitate the implementation of energy efficiency measures to achieve regulatory compliance.

The calculation of EEXI, although complex, is highly crucial in steering the maritime industry towards greener and more sustainable practices. Specialized software and tools, often provided by classification societies, facilitate accurate calculations and assist ship owners and operators in navigating the intricacies of compliance with energy efficiency regulations.

## Result and Discussion

### Resistance and Powering

This research investigates a container ship with a capacity of 100 TEUs. The ship is modelled and subsequently, a towing test is conducted to collect resistance data. The results obtained from this method are considered reliable in representing the actual resistance experienced by the ship. Table 2 presents the resistance data obtained from the towing test. At the maximum speed of 11 knots, the resistance is approximately 92.5 kN, while at the lowest speed of 8.5 knots, it yields around 43.4 kN, which is nearly half of the result at the maximum speed.

**Table 2.** Resistance of the ship from towing tank data

| VS (Knots) | RS (KN) | BHP (HP) |
|---|---|---|
| 5 | 20,019 | 200,081 |
| 5,5 | 22,753 | 239,8521 |
| 6 | 25,860 | 287,5286 |
| 6,5 | 29,391 | 344,682 |
| 7 | 33,405 | 413,1961 |
| 7,5 | 37,966 | 495,3291 |
| 8 | 43,400 | 590,974 |
| 8,5 | 48,800 | 710,497 |
| 9 | 55,200 | 849,941 |
| 9,5 | 63,400 | 1029,225 |
| 10 | 72,900 | 1245,030 |
| 10,5 | 81,900 | 1470,796 |
| 11 | 92,500 | 1739,722 |

After obtaining the resistance data, the next step involves calculating the engine power requirements. Engine power must be calculated, taking into account power losses through the gearbox and shaft until reaching the propeller. Additionally, the engine power should incorporate a 15% margin to accommodate uncertainties at sea. This is done to be prepared for unforeseen conditions. Figure 1 illustrates the relationship between resistance and power concerning speed. The results indicate that an increase in speed will also result in an increase in the power required by the ship. The maximum speed will necessitate approximately 1300 kW of power.

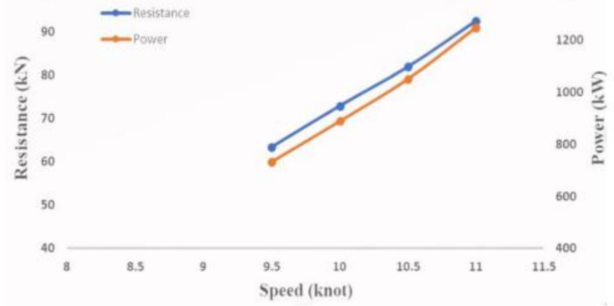
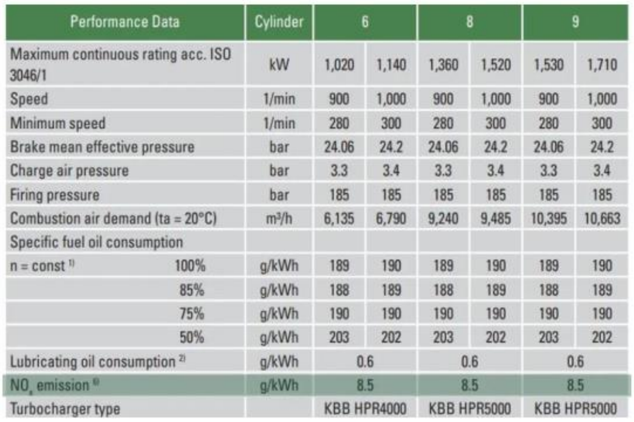


**Figure 1.** Resistance and Power chart

## Slow Steaming Effect on Fuel Consumption

Once the engine power is estimated, the selection of the main engine can commence. The chosen main engine should align with the earlier engine power calculations. The selected main engine has a power rating of 1360 kW, as indicated in figure 2. The technical data of this engine specifies the specific fuel oil consumption (SFOC) with engine load as a parameter. The SFOC values in the table are nonlinear within the engine load range of 50% to 100%. In addition to SFOC, the technical data also provides information on NOx emissions, indicating the amount of nitrogen emissions generated by the main engine.



| Performance Data | Cylinder | 6 | | 8 | | 9 | |
|---|---|---|---|---|---|---|---|
| Maximum continuous rating acc. ISO 3046/1 | kW | 1,020 | 1,140 | 1,360 | 1,520 | 1,530 | 1,710 |
| Speed | 1/min | 900 | 1,000 | 900 | 1,000 | 900 | 1,000 |
| Minimum speed | 1/min | 280 | 300 | 280 | 300 | 280 | 300 |
| Brake mean effective pressure | bar | 24.06 | 24.2 | 24.06 | 24.2 | 24.06 | 24.2 |
| Charge air pressure | bar | 3.3 | 3.4 | 3.3 | 3.4 | 3.3 | 3.4 |
| Firing pressure | bar | 185 | 185 | 185 | 185 | 185 | 185 |
| Combustion air demand (ta = 20°C) | m³/h | 6,135 | 6,790 | 9,240 | 9,485 | 10,395 | 10,663 |
| Specific fuel oil consumption | | | | | | | |
| n = const 1) 100% | g/kWh | 189 | 190 | 189 | 190 | 189 | 190 |
| 85% | g/kWh | 188 | 189 | 188 | 189 | 188 | 189 |
| 75% | g/kWh | 190 | 190 | 190 | 190 | 190 | 190 |
| 50% | g/kWh | 203 | 202 | 203 | 202 | 203 | 202 |
| Lubricating oil consumption 2) | g/kWh | 0.6 | | 0.6 | | 0.6 | |
| $NO_x$ emission 6) | g/kWh | 8.5 | | 8.5 | | 8.5 | |
| Turbocharger type | | KBB HPR4000 | | KBB HPR5000 | | KBB HPR5000 | |

**Figure 2.** Main Engine Technical Data

Once the engine power is estimated, the selection of the main engine can commence. The chosen main engine should align with the earlier engine power calculations. The selected main engine has a power rating of 1360 kW, as indicated in Figure 2. The technical data of this engine specifies the specific fuel oil consumption (SFOC) with engine load as a parameter. The SFOC values in the table are nonlinear within the engine load range of 50% to 100%. In addition to SFOC, the technical data also provides information on NOx emissions, indicating the amount of nitrogen emissions generated by the main engine.

The nonlinearity of SFOC is depicted in Figure 2, showing an increase in SFOC as the engine load approaches the maximum. Consequently, the lowest point of SFOC does not occur at the lowest engine load rating but falls within the engine load range of 75% to 85%. Considering the power required for the sailing vessel, the ship's speed is then utilized to estimate the corresponding engine load required to operate the ship.

Moving on to the next phase involves the intricate process of calculating the sailing route for the maritime journey under consideration. In this particular study, the chosen shipping route spans from Surabaya to Ambon, encompassing an estimated route length of approximately 1018 nautical miles. This route selection is pivotal, as it sets the stage for evaluating the vessel's operational dynamics and efficiency. The calculated sailing duration takes into meticulous account the time allocated for port activities, adding a layer of precision to the overall assessment.

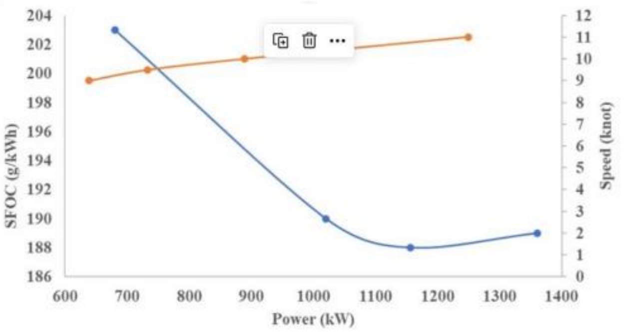


**Figure 3.** SFOC and Speed graph

**Figure 4.** Sailing route

By leveraging the speed values derived in the preceding calculations, it becomes possible to ascertain the temporal aspect of the maritime venture. This entails determining the duration required for the ship to complete a single voyage from the embarkation point in Surabaya to its destination in Ambon. Additionally, this temporal consideration is extended to factor in the time spent at various ports along the route. The amalgamation of these temporal elements provides a comprehensive outlook on how efficiently the vessel can navigate through the selected route.

Furthermore, armed with the knowledge of the time needed for one voyage, attention can now be directed towards assessing the cumulative impact on the annual operational schedule of the ship.

By extrapolating the voyage duration to an annual timeframe, it becomes feasible to estimate the total number of voyages the ship can successfully undertake within the span of a year as shown in Table 3 above. This crucial information not only aids in understanding the vessel's yearly operational capacity but also forms an integral part of strategic planning for maritime logistics and scheduling. Consequently, this comprehensive analysis contributes significantly to the overarching goal of optimizing the efficiency and effectiveness of the maritime transport system under scrutiny.

**Table 3.** Ship estimated voyage

| Engine Load | Speed | Daily Voyage | Yearly Voyage |
|---|---|---|---|
| 92% | 11 Knot | 10,75 | 33 |
| 77% | 10.5 Knot | 11,08 | 32 |
| 65% | 10 Knot | 11,5 | 31 |
| 54% | 9.5 Knot | 12 | 30 |

**Table 4.** Fuel consumption data

| Engine Load | Fuel Consumption (liter) | Fuel Consumption (Rp) |
|---|---|---|
| 92% | 46486 | Rp33.748.836.000,00 |
| 77% | 40914 | Rp28.803.667.200,00 |
| 65% | 37559 | Rp25.615.238.000,00 |
| 54% | 33708 | Rp22.247.280.000,00 |

With the estimated voyage data and engine SFOC, fuel consumption for sailing can be calculated. Table 4 illustrates the reduction in oil fuel consumption corresponding to the decrease in engine load. It is evident that slow steaming, in terms of oil fuel consumption, results in fuel cost reduction. The oil prices used to estimate the cost of oil fuel consumption are based on the latest available data as of December 2023.

### Slow Steaming Effect on Emission

The concept of slow steaming is not only related to fuel consumption but also to the emissions produced by the engine, including carbon, sulfur, and nitrogen emissions. Considering the potential impact of emissions on human life, it is logical to calculate and minimize these emissions. An alternative approach involves imposing charges on emission producers, such as the Nitrogen tax in China ranging from 1263 yuan to 12630 yuan. Setting a specific price for the Nitrogen tax can also result in a reduction in carbon and sulfur taxes, as these emissions are produced concurrently. Technical data for the main engine records nitrogen emissions at 8.5 g/kWh.

**Table 5.** Emission and usage of nitrogen in a year

| Engine Load | Yearly Emission (ton) | Yearly Nitrogen Tax |
|---|---|---|
| 92% | 66 | Rp1.815.000.000,00 |
| 77% | 56 | Rp1.540.000.000,00 |
| 65% | 48 | Rp1.320.000.000,00 |
| 54% | 41 | Rp1.127.500.000,00 |

Table 5 and Figure 5 illustrate the decrease in emissions at the beginning of the journey with a decrease in engine load, showing how slow steaming also contributes to emission reduction. The maximum annual nitrogen emissions reach 66 tons, with a tax of around 1.8 million rupiah. Meanwhile, the minimum nitrogen emissions reach 41 tons, representing a reduction of 25 tons per year, with a tax of about 1.1 million rupiah. This data indicates a significant reduction in nitrogen emissions and associated taxes over the course of a year.

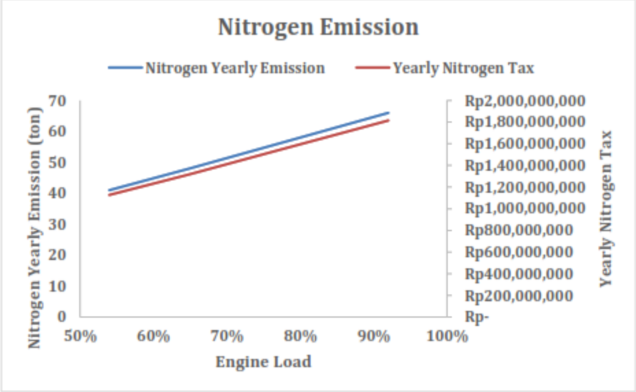


**Figure 5.** Nitrogen Emission

After calculating nitrogen emissions based on the provided data, the next step involves the calculation of taxes to address the environmental impact generated by the ship. From the results of these calculations, it is evident that paying taxes for nitrogen emissions can be a proactive step in reducing the negative impact on water and air environments. The calculation results indicate a correlation between paying nitrogen taxes and the reduction of carbon and sulfur emissions. This phenomenon is linked to the implementation of tax policies that encourage the use of more environmentally friendly fuels and more efficient engine technologies. By paying nitrogen taxes, shipping companies indirectly contribute to reducing the carbon and sulfur footprint, demonstrating a commitment to sustainable practices in the shipping industry.

It is important to note that these findings are supported by information found in several journals highlighting the importance of tax policies as effective instruments in addressing emission issues in the shipping sector. Research results from these journals indicate that by paying nitrogen taxes, shipping companies can play a key role in achieving overall greenhouse gas emission reduction targets. Therefore, paying nitrogen taxes is not only the responsibility of shipping companies to comply with regulations but can also be considered an investment in efforts to maintain environmental sustainability and contribute positively to global climate change mitigation.

**Table 6.** EEXI calculation result

| Speed (knot) | SFOC (g/kWh) | Engine Power (kW) | Capacity (ton) | CO2 Conversion | EEXI Value |
|---|---|---|---|---|---|
| 11 | 188,35 | 1249 | 2200 | 3.206 | 31166,06552 |
| 10,5 | 188,94 | 1051 | 2200 | 3.206 | 27559,21875 |
| 10 | 194,87 | 889 | 2200 | 3.206 | 25245,16555 |
| 9,5 | 200,27 | 733 | 2200 | 3.206 | 22518,17557 |

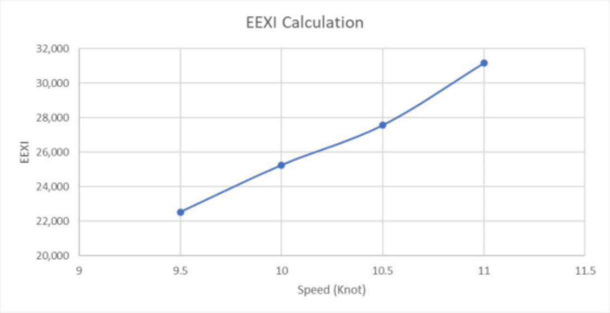


**Figure 6.** EEXI Graph

The calculation of the Existing Ship Energy Efficiency Index (EEXI) has been executed as an essential step in optimizing energy efficiency and mitigating the environmental impact caused by ships. EEXI, as a normative metric, serves as a critical assessment of the extent to which a ship complies with the energy efficiency regulations imposed by the International Maritime Organization (IMO). The EEXI calculation process involves several methodological phases, including defining a reference line for a specific ship category, applying correction factors to adjust technical characteristics, and computing based on the Energy Efficiency Design Index (EEDI).

The significance of these EEXI calculations resonates within the context of global initiatives to reduce greenhouse gas emissions in the shipping sector. By reinforcing energy efficiency standards imposed on ships, EEXI calculations become a vital driver for technological advancements and the implementation of sustainable practices within the maritime industry. Furthermore, these regulations aim to provide incentives for ship owners to modernize and enhance the efficiency of their fleets.

The results of EEXI calculations provide tangible values for the Ship Energy Efficiency Index, which are then compared with the EEXI values mandated by IMO regulations. The conformity or even surpassing of these EEXI values becomes a critical indicator of a ship's compliance with regulations and positive contributions to global maritime environmental protection efforts. Conversely, non-compliance with the prescribed EEXI values allows ship owners to evaluate and implement corrective actions or energy efficiency technologies as an integral part of a long-term strategy to ensure compliance and sustainability of their fleets.

## Conclusion

The results of the analysis from several conducted variations can be summarized as follows:

1. For the Round-trip Full Load scenario, it is concluded that the ship achieves the highest profit at 77% engine load or a speed of 10.5 knots, yielding a profit of Rp50,376,332,800.00.
2. In the Round-trip 1.5 Load scenario, it is determined that the ship attains the maximum profit at 54% engine load or a speed of 9.5 knots, resulting in a profit of Rp21,245,220,000.00.
3. Bunkering costs, calculated linearly with the mentioned data, constitute 30 - 50% of the total cost.
4. The maximum value from the EEXI calculation is observed at a speed of 11 knots with a value of 31,166.06552, and the minimum value is at a speed of 9.5 knots with a value of 22,518.17557.
5. This research highlights the importance of operational flexibility for achieving maximum profit. By examining the optimal speed and engine load for each scenario, it can be concluded that ships capable of adapting to changes in operational conditions will be better positioned to maximize financial outcomes. Therefore, management that is responsive to market dynamics and operational requirements is key to achieving sustainable economic efficiency.

## References

[1] P. Cariou, Is slow steaming a sustainable means of reducing CO2 emissions from container shipping? Transportation Research Part D, *Transport and Environment*. **16(3)** (2011) 260–264. DOI: 10.1016/j.trd.2010.12.005

[2] P. Cariou, C. Ferrari, F. Parola & A. Tei, Slow steaming in the maritime industry. In The Routledge Handbook of Maritime Management (pp. 140–153), *Routledge*. (2019).
DOI: 10.4324/9781315617138-9

[3] M.A.F. Cepeda, L/F. Assis, L.G. Marujo & J.-D. Caprace, Effects of slow steaming strategies on a

ship fleet, *Marine Systems & Ocean Technology*. **12(3)** (2017) 178–186. DOI: 10.1007/s40868-017-0033-3

[4] J. Faber, D. Nelissen, G. Hon, H. Wang & M. Tsimplis, Regulated slow steaming in maritime transport: An assessment of options, costs and benefits, *CE Delft*. (2012).

[5] J. Ksciuk, S. Kuhlemann, K. Tierney, & A. Koberstein, Uncertainty in maritime ship routing and scheduling: A Literature review, *European Journal of Operational Research*. **308(2)** (2023) 499–524. DOI: 10.1016/j.ejor.2022.08.006

[6] C.-Y. Lee, H.L. Lee, & J. Zhang, The impact of slow ocean steaming on delivery reliability and fuel consumption, *Transportation Research Part E: Logistics and Transportation Review*. **76** (2015) 176–190. DOI: 10.1016/j.tre.2015.02.004

[7] M. Maloni, J.A. Paul, & D.M. Gligor, Slow steaming impacts on ocean carriers and shippers, *Maritime Economics & Logistics*. **15(2)** (2013) 151–171. DOI: 10.1057/mel.2013.2

[8] M. Zanne, M. Počuča, & P. Bajec, Environmental and economic benefits of slow steaming, *Transactions on Maritime Science*. **2(2)** (2013) 123–127. DOI: 10.7225/toms.v02.n02.005

[9] Y. Zhao, J. Zhou, Y. Fan, & H. Kuang, Sailing speed optimization model for slow steaming considering loss aversion mechanism, *Journal of Advanced Transportation*. **2020** (2020) 1–11. DOI: 10.1155/2020/2157945