

A semi-empirical operational performance prediction for anchor handling tug supply (AHTS) vessel

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Abstract. Speed reduction is a practice way for the ship operator to increase efficiency and reduce Green House Gas (GHG) emission in the shipping industry. In this paper, using Kwon's method to predict the added resistance caused by wave and wind for specific vessel, and a cubic function of speed and fuel rate to predict the total fuel consumption at varyig speed, encounter angles and various sea state during her voyage. This study aims to determine the optimum operational speed for minimizing fuel consumption using the energy-efficiency operational indicator (EEOI) concept. Using two anchor handling tug supply (AHTS) vessel as the research object, the comparison between the recorded and predicted EEOI values indicates the influence of hull fouling, propeller condition, and engine degradation. The results show that AHTS A had a 5.91% prediction error over 14 months, while maintenance during dry docking (AHTS B) reduced the error by 6.57%. A 0.5-knot speed reduction decreased the fuel consumption by 0.5%, but increased the sailing time by 4.88%. Thus, lower speeds improve the fuel efficiency, although longer voyage durations are required. Environmental conditions also have a significant impact on the fuel performance.

Keywords : Ship emission, anchor handling tug supply, energy efficiency, speed reduction

1 Introduction

Offshore support vessels represent the most rapidly expanding category within the offshore sector, and this trend is anticipated to persist throughout 2015–2020. Heightened international concern for the preservation of sensitive environments, along with potential binding commitments to reduce greenhouse gas emissions, are expected to stimulate demand in this segment and accelerate the adoption of advanced technologies. The worldwide demand for fossil fuels is expected to continue to grow in the years ahead. Offshore spending

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is predicted to rise over the next 10–20 years, with an annual growth of approximately 10–15%. As the offshore industry grows, there is a need for specialized vessels to support offshore activities. An Anchor Handling Tug Supply (AHTS) vessel is a powerful, multi-purpose offshore support ship used in the oil and gas industry for towing rigs, deploying/recovering rig anchors, and transporting supplies such as fuel, water, and equipment. It features strong winches, large decks, high bollard pull, and often Dynamic Positioning (DP) systems for precise station-keeping in demanding offshore environments, which are the fastest-growing type in the sector, with anchor handling tug supply vessels (AHTS) showing the strongest growth of all [1]. As shown in **Fig. 1**, the expected growth of the AHTS vessel is about 918 units in 2020 or about 24.5% compared to 2012, while the overall offshore vessel growth is 3,580 units or about 31.5% for the same year period.

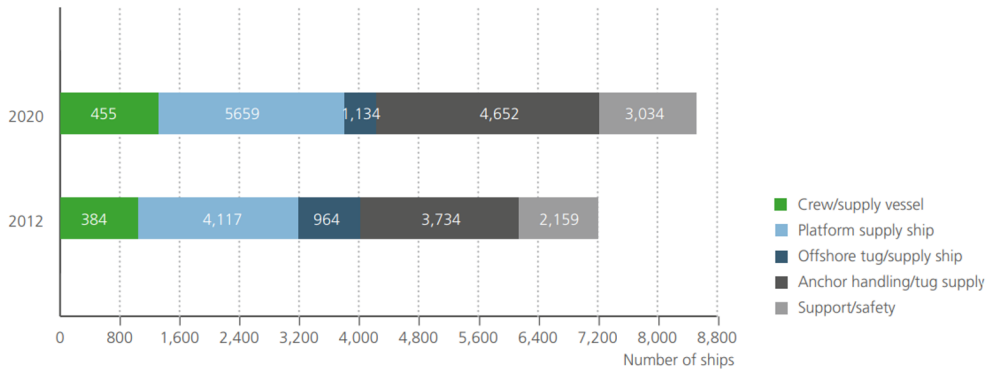


Fig. 1. Offshore fleet for 2012 and the forecast for 2020 according to Det Norske Veritas (DNV) [1].

The shipping industry is already tightly regulated, and in this decade, it will face even more rules with major economic and operational consequences. One of the biggest challenges for companies is handling the combined impact of these regulations. Those that fail to make the right strategic decisions may put their long-term survival at a serious risk.

To meet its climate goals, the IMO has proposed a set of measures in two main parts. The first is a technical measure, a fuel standard aimed at gradually lowering the GHG intensity of marine fuels. The second is an economic measure: a pricing system for maritime GHG emissions that may be tied directly to the fuel intensity standard. Work on these measures is ongoing at the IMO, with adoption planned for 2025 and implementation expected by mid-2027 [2]. The aim of this study is to propose the use of an energy efficiency operational indicator (EEOI) as the basis of ship performance. Furthermore, the ship speed should be recommended to reduce fuel within the time bond.

Fig. 2 illustrates the regulatory timeline for international shipping emissions from 2023 to 2027. It outlines the implementation of the energy efficiency existing index (EEXI), ship energy efficiency management plan (SEEMP), and carbon intensity index (CII) ratings in 2023, followed by enhanced data collection systems and GHG fuel standards in 2024–2025. The process progresses towards potential measures, such as IMO carbon pricing and GHG fuel standards, by 2027, supported by continuous reviews and impact assessments.

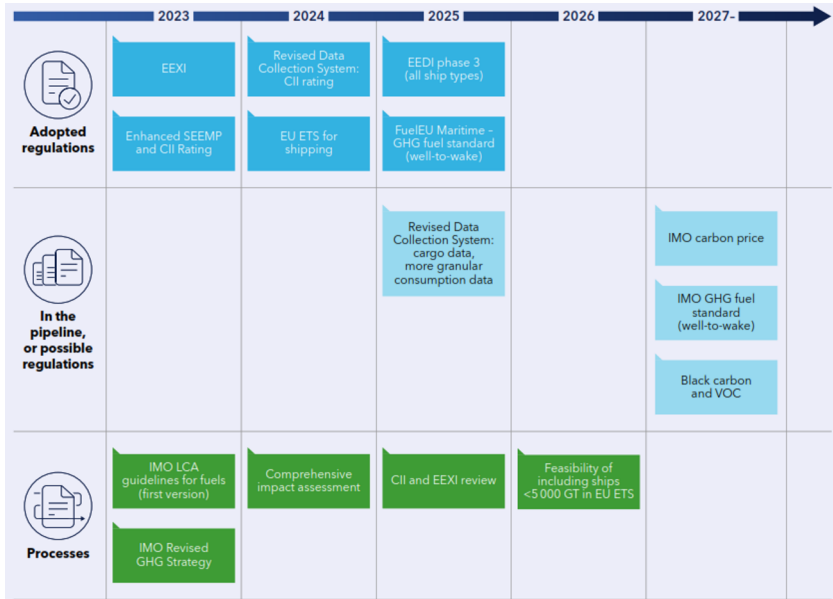


Fig. 2. GHG regulatory timeline towards 2030, highlighting major regulatory development [2].

2 Method

To bring consistency and oversight into ship efficiency measures, the IMO introduced the Ship Energy Efficiency Management Plan (SEEMP) in 2013 [3]. This plan serves as a framework for improving fuel efficiency across every stage of ship operations [4]. Under IMO rules, shipowners and operators are encouraged to evaluate and apply new technologies and practices to boost performance. Along with operational planning, monitoring fuel use and collecting data for future improvements are crucial for achieving ongoing efficiency gains. One of the key tools used for this is the energy-efficiency operational indicator (EEOI) [5].

The Energy Efficiency Operational Indicator (EEOI) indicates how efficiently a ship operates, essentially measuring how much cargo is moved for the amount of fuel used. It is calculated using CO₂ emissions (from fuel consumption), the cargo carried, and the distance sailed during each voyage over a set period, providing a clear and standardized way to express a ship’s energy performance, in which EEOI is calculated as the ratio of a ship’s total CO₂ emissions during real operations to the actual transport work, measured in terms of passengers or cargo carried [6].

$$EEOI = \frac{FC}{m_{\text{cargo}} \times D} \tag{1}$$

FC represents Fuel Consumption in tons, m_{cargo} is the ton of ship carried, and D is the sailing distance in nautical miles. EEOI stresses the need to assess a ship’s energy performance in real sailing conditions, where rough seas often cause unavoidable speed loss. To improve efficiency, both ship designers and operators need dependable methods to measure and account for these losses [7]. The environmental condition is described by the Beaufort Number (BN).

Using two AHTS as the research objects, a newly built and old vessel that has already performed dry docking activities. Samples were taken to compare the ship operational performance for the new and old vessel-based EEOI approaches.

Daily basis data, known as vessel daily reports or noon reports, were collected. The types of data fields that are included in the vessel daily reports cover the date/time of the reports, ship position, time of arrival and departure, wind speed and direction, main engine rpm, and total main engine fuel consumption. We also used passage plan data consisting of the ship planning route.

Table 1. Beaufort Number (BN) represent a range of wave height and sea condition.

BN	Description	Wind Speed (Knot)	Wave height (ft)	Sea Condition
0	Calm	< 0.6	0	Flat
1	Light air	0.6 – 3.0	0 – 1	Ripples without crest
2	Light Breeze	3.0 – 6.4	1 – 2	Ripples without crest
3	Gentle Breeze	6.4 – 10.6	2 – 3.5	Large wavelength, crest begin to break
4	Moderate Breeze	10.6 – 15.5	3.5 – 6.0	Small wave with breaking crest
5	Fresh Breeze	15.5 - 21	6.0 – 9.0	Moderate waves of some length
6	Strong Breeze	21 – 26.9	9.0 – 13.0	Long wave beginto form, white foam crest
7	High wind, Moderate gale, near gale	26.9 – 33.4	13.0 – 19.0	Sea heaps up
8	Gale, Fresh gale	33.4 – 40.3	18.0 – 25.0	Streaks along wind direction
9	Strong/severe gale	40.3 – 47.6	23.0 - 32	Foam is blown along wind direction
10	Storm, whole gale	47.6 – 55.3	29 - 41	Very high waves with overhanging crest
11	Violent storm	55.3 – 63.4	37 - 52	Exceptionally high waves
12	Hurricane	>= 63.4	>= 46	Huge waves, se ais completely white foam and spray

Table 1 it correlates wind speed (in knots) and wave height (in feet) with descriptive sea states ranging from calm (BN 0) to hurricane (BN 12). The scale provides a standardized reference for evaluating maritime weather conditions and their effects on the sea surface.

The added resistance model is a practical method used to estimate the speed at which a displacement ship loses when facing rough weather conditions, including irregular waves and wind. Its strength is that it is simple and easy to use. Weather effects are shown as speed loss, which is calculated by comparing the speed of a ship in real sea conditions with its expected speed in calm water. Kwon’s method is commonly used to model this added resistance[8].

$$\frac{\Delta V}{V_1} 100\% = C_\beta C_U C_{\text{form}} \tag{2}$$

Where,

V_1 : Design (nominal) ship speed under calm water conditions (m/s).

V_2 : Actual ship speed in weather condition, in m/s.

ΔV : $V_1 - V_2$ Absolute speed loss

C_β : Coefficient reduction due to direction

C_U : speed reduction coefficient dependent on ship’s block coefficient C_B and Beaufort Number (BN)

C_{Form} : Coefficient of ship’s form.

Ships keep daily records of their operations in logs or reports, often called *noon reports* because they are usually written once a day at midday. These reports typically include details such as the date and time, ship’s position, estimated time of arrival, departure or arrival port, distance covered, average speed, draft, Beaufort Number, wind direction, and ship’s daily fuel use. However, there is no universal standard for what these reports must contain; therefore, the details often vary between companies. The data also carry a lot of uncertainty, caused by the way measurements are taken, the type of measurements, possible human error, and assumptions made during analysis [9].

AHTS A with Length overall (Loa) 59.25 m, breadth 14.95 m, Depth 4.95 m, 1678 GT, 2x2,575 BHP of main engine with 13 knot of ship’s design speed and 14 months of operation, compared with AHTS B Loa 57.7 m, breadth 12.2 m, Depth 4.3 m, 957 GT 2x2,400 BHP of main engine and 10 knot of design speed with 13 months of operational included with dry-docking.

3 Result and discussion

The Energy Efficiency Operational Indicator (EEOI), shown in Equation (1), is calculated based on the fuel consumption and distance sailed. For the same ship and fuel types, the CO₂ conversion factor and gross tonnage remained constant. The EOI is affected by fuel consumption, which can vary even on the same route depending on the weather and sea conditions at the time of sailing [10]. These conditions often cause speed loss, meaning that the ship takes longer to complete the voyage and uses more fuel even on an identical route. For this reason, the environmental effects are used to calculate the speed loss, which is then used to estimate the predicted EEOI. This predicted value was later compared with the actual EEOI based on data collected directly from the ship. An example of the calculation of speed loss is presented in **Table 2** for a given distance, course, wind speed, and direction. Speed loss is represented as the percentage of reduced speed based on ship speed in calm water.

Table 2. Speed loss calculation of AHTS A with different encounter angle and sea conditon.

Dist (nm)	Course (°)	Wind (average)			Encounter Angle		BN	C_B	C_{form}	$\Delta V/V1$ 100%	V_2 (knot)	Time (h)
		dir	(°)	Speed	(°)	dir.						
1.10	308	N	0	12	128	Beam Sea	4	0.33	16.195	0.3814	13.0	0.08
17.40	327	N	0	12	147	Beam Sea	4	0.33	16.195	0.3814	13.0	1.34
12.20	289	N	0	12	109	Beam Sea	4	0.33	16.195	0.3814	13.0	0.94
18.50	341	N	0	12	161	Following Sea	4	-0.04	16.195	0.0462	13.0	1.42
14.40	358	N	0	12	178	Following Sea	4	-0.04	16.195	0.0462	13.0	1.11
14.20	10	N	0	12	170	Following Sea	4	-0.04	16.195	0.0462	13.0	1.09
25.90	49	N	0	12	131	Beam Sea	4	0.33	16.195	0.3814	13.0	2.00

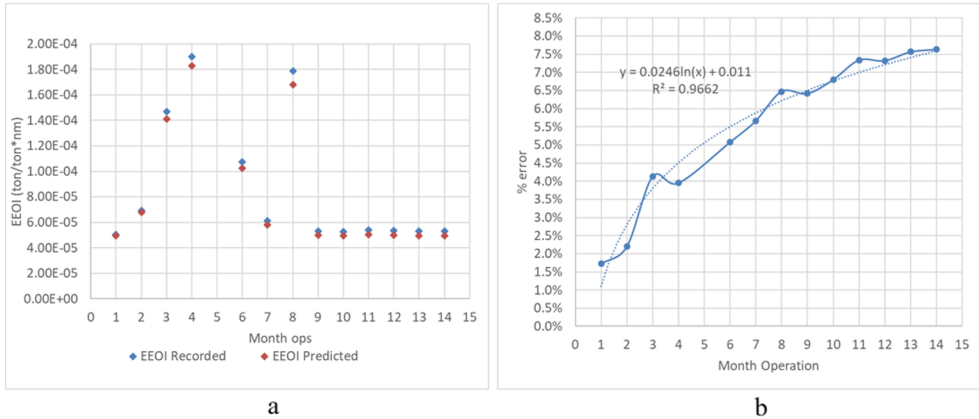


Fig. 3. (a) Comparison between monthly predicted EEOI and recorded EEOI of AHTS A ; (b) error between predicted total fuel consumption of each monthly voyage and recorded one for AHTS A.

Fig. 3 shows a comparison of the recorded and predicted energy efficiency operational indicators (EEOI) for AHTS A over 14 months of operation. The graph on the left illustrates that the predicted EEOI values closely followed the recorded data trend. The graph on the right presents the percentage error, which increases logarithmically with the operation time. The percentage error value for AHTS A closely followed a logarithmic relationship, with an R^2 value of 0.9662. Based on this approach, the error in the first month was 1.72%, while in the 14th month, it increased to 7.63%, resulting in a difference of 5.91%. These findings serve as a reference for calculating and determining the ship’s optimum speed to achieve lower fuel consumption while maintaining an acceptable voyage duration.

Table 3. EEOI of AHTS B two month operation before docking and thirteen month operation after dry-docking.

Month ops	Distance (NM)	Actual EEOI	Predicted EEOI	Error (%)
0	51.30	1.70E-04	1.52E-04	11.591%
1	51.30	2.58E-04	2.30E-04	11.740%
DRY-DOCKING				
1	51.3	1.40E-04	1.33E-04	5.164%
2	58.05	1.41E-04	1.34E-04	5.457%
3	58.05	1.39E-04	1.31E-04	6.398%
4	58.05	1.39E-04	1.29E-04	7.398%
5	58.05	1.39E-04	1.29E-04	7.479%
6	58.05	1.43E-04	1.32E-04	8.140%
7	58.05	1.43E-04	1.32E-04	8.630%
8	58.05	1.43E-04	1.32E-04	8.140%
9	58.05	1.45E-04	1.34E-04	8.647%
10	58.05	1.73E-04	1.58E-04	9.385%
11	58.05	1.45E-04	1.34E-04	8.647%
12	58.05	1.45E-04	1.34E-04	8.854%
13	58.05	1.45E-04	1.34E-04	8.452%

Table 3 presents a comparison between the actual and predicted EEOI values along with the predicted fuel consumption and error percentage for AHTS B. The results showed that prediction errors ranged between 5 and 11%, with higher discrepancies observed before the docking period. After docking, the predicted EEOI aligned more closely with the actual data, indicating improved model accuracy and operational consistency. Owing to the limited availability of operational data prior to dry-docking, the error values before dry-docking cannot provide a clearer insight. However, they were higher than the error values recorded after the vessel underwent dry docking.

It can be observed that the error value prior to dry-docking reached 11.74%. After dry docking, this error decreased to approximately 5.16%, representing a reduction of approximately 6.57%. However, as shown in **Fig. 4**, the error values gradually increased as the vessel continued to operate. By the 13th month of the post-dry-docking operation, the error had increased by 3.28% to approximately 8.45%. This increase can be approximated using a logarithmic function with an R^2 value of 0.9068, indicating improved prediction accuracy and more stable vessel performance after maintenance.

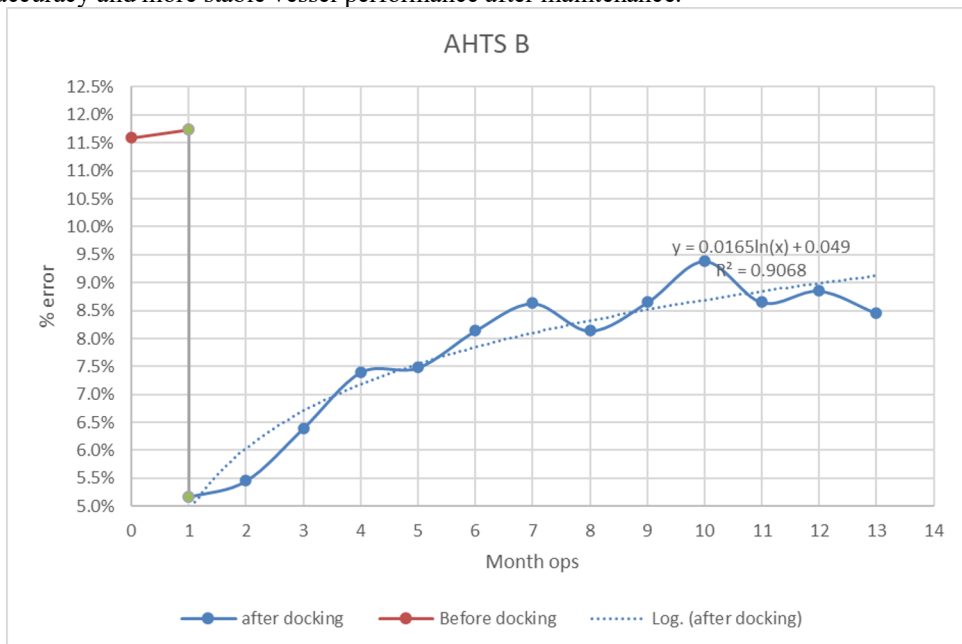


Fig. 4. error between predicted total fuel consumption of each monthly voyage and recorded one for AHTS B two month operation before dry-docking and thirteen month operation after dry-docking.

This shows the usual pattern of rising fuel consumption caused by hull and propeller fouling, along with engine wear [9]. Currently, because there are no detailed dry-docking or engine maintenance reports, we cannot clearly determine how much of the increase comes from fouling and the extent of engine degradation. Nevertheless, identifying this time-related increase in fuel use provides useful insights into their combined effect on ship performance.

Reducing ship speed is one of the most effective ways of reducing greenhouse gas (GHG) emissions. Because the link between speed, power demand, and fuel consumption is nonlinear, slowing a vessel by $x\%$ often leads to a fuel and emission reduction that is larger than $x\%$ [11]. Speed reduction is an operational measure that can effectively reduce fuel consumption. In this study, we investigated strategies to reduce fuel consumption during supply vessel operations through speed optimization. For this purpose, we consider the fuel consumption per unit of time during sailing, expressed as [12]:

$$FC(v) = \left(\frac{FC_0}{v_0^3} \right) v^3 \quad (3)$$

The purpose of speed optimization is to enable the ship to operate with lower fuel consumption compared to its previous operation. In practice, the fuel consumption tends to increase with speed, following a nearly cubic relationship. Therefore, a mathematical model is required to estimate total fuel consumption for a given voyage distance. The outcome of this optimization is reflected in the EEOI value, where a lower EEOI indicates more efficient fuel use throughout the voyage. A speed reduction of 0.5 knots results in a 0.5% decrease in fuel consumption, while increasing the sailing time by 4.88%, as shown in the graph below.

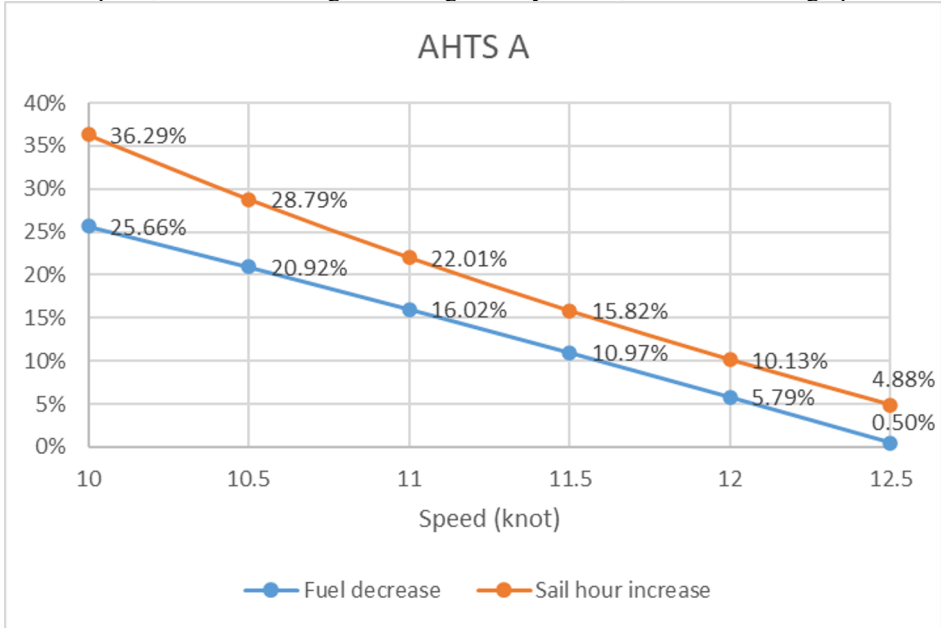


Fig. 5. Fuel consumption varying speed reduction of AHTS A and sail hour increase as its consequences

Speed reduction was then simulated using the same distance, course, and environmental conditions. **Fig. 5** illustrates the relationship between the vessel speed and the percentage of fuel decrease as well as the sailing-hour increase for AHTS A. As the speed increased from 10 to 12.5 knots, both fuel savings and sailing hour gains declined significantly. At 10 knots, the fuel decrease reached 25.66%, whereas the sailing hour increase was 36.29%. These values dropped to 0.5% and 4.88%, respectively, at 12.5 knots. This trend indicates that operating at lower speeds substantially improves the fuel efficiency, although it results in longer voyage times.

4 Conclusion

This study demonstrated that vessel operational efficiency, as represented by the Energy Efficiency Operational Indicator (EEOI), can be effectively predicted with a relatively low error margin. A comparison between the recorded and predicted EEOI values shows a strong correlation, indicating that the applied model can capture the vessel's operational performance trend with high reliability. Post-docking analysis revealed improved accuracy and stability, suggesting that maintenance activities played a significant role in enhancing energy performance.

Furthermore, the relationship between vessel speed, fuel consumption, and sailing hours highlights a clear trade-off between the operational efficiency and voyage duration. Operating at moderate speeds of approximately 10–11 knots provides the most balanced conditions for fuel economy and productivity. Overall, the findings provide valuable insights for optimizing ship operations and contribute to broader efforts to reduce greenhouse gas emissions in the maritime sector.

Future research should focus on developing a more comprehensive energy efficiency prediction model that incorporates real-time operational parameters such as sea state, load condition, and engine performance. Additional studies could also explore optimization algorithms or machine learning approaches to improve the prediction accuracy and provide decision-support tools for ship operators to achieve lower EEOI values.

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