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OPERATIONAL REALITIES VS. STATIC ASSUMPTIONS: RETHINKING FUEL EFFICIENCY METRICS FOR THE GFI TARGET

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ABSTRACT
This study examines the operational efficiency and greenhouse gas (GHG) emissions of offshore support vessels, comparing the validation mechanisms of Proxy A and the Energy Operational Index (EOI) within the context of the GHG Fuel Intensity Indicator (GFI). The results indicate that the EOI surpasses Proxy A in accuracy by incorporating dynamic operational data, such as engine loads in different modes, and correcting discrepancies in reported fuel consumption. In a case study of a vessel operating in tropical Brazilian waters, low engine loads during Dynamic Positioning mode (19%) revealed inefficiencies, while higher loads in Navigation mode (68.66%) demonstrated improved performance. The findings highlight the value of the EOI in ensuring reliable emissions data and its strategic role in supporting sustainable practices and realistic decarbonization goals for the maritime industry.

Keywords: Energy Efficiency. Offshore Support Vessels. Greenhouse Gases (GHG). Greenhouse Gas Fuel Indicator (GFI). Energy Operational Index (EOI). Dynamic Positioning (DP). International Maritime Organization (IMO). Fuel Consumption. Efficiency Metrics. Sustainability. Decarbonization. Maritime Transportation.

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INTRODUCTION

The growing global concern about climate change and its environmental impacts has drawn attention to the need for reducing greenhouse gas (GHG) emissions across all economic sectors, including maritime transport. The International Maritime Organization (IMO) has established regulations aimed at promoting energy efficiency and reducing emissions in the shipping industry, aligning the sector with global sustainability and environmental protection goals [5,8,9].

Offshore support vessels, classified by the IMO as offshore ships, play a crucial role in the global maritime landscape. Representing 6.3% of the global fleet, according to the IMO's Fourth GHG Study, and with more than 7,555 units in operation, these vessels are essential for offshore supply chains and logistics. According to IMCA, this category includes over 45 distinct types of vessels, underscoring their operational diversity. Despite their strategic importance, the assessment of energy efficiency for these vessels remains underdeveloped, as indicators such as the Energy Efficiency Design Index (EEDI) and the Energy Efficiency Index for Existing Ships (EEXI) traditionally exclude offshore operations.

Resolution MEPC 391(81), adopted in 2024, introduced the 2024 Guidelines on Life Cycle GHG Intensity of Maritime Fuels (2024 LCA Guidelines), marking a regulatory milestone for energy efficiency. This resolution proposes the continuous monitoring of vessel emissions, comparing them to developing performance curves. Vessels failing to meet the established standards may face financial penalties, reinforcing the urgency to robustly and specifically address the energy efficiency of offshore vessels [11,12,13].

Recently, the GHG Fuel Indicator (GFI), part of the GHG Fuel Standard Resolution (GFS), expanded its scope to include offshore vessels. Recognizing the peculiarities of these operations, which often involve intensive use of Dynamic Positioning (DP) systems, Brazil submitted a proposal for the Efficiency Offshore Indicator (EOI) during the 17th IMO GHG Intercession. This voluntary validation mechanism was designed to complement the GFI by integrating data from specific operational modes of offshore vessels.

In this context, the need arises for a comparative analysis of different energy efficiency indicators, focusing on the unique characteristics of offshore vessels. This study aims to investigate the applicability of the EOI as a validation mechanism, highlighting its capacity to address gaps left by traditional methods. The proposal considers the unique operational conditions of these vessels and examines how the EOI can contribute to a more realistic understanding adapted to the complexities of offshore operations.

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OBJECTIVE AND CONTRIBUTIONS

The objective of this work is to perform a comparative analysis of the Proxy A and EOI indicators, evaluating their effectiveness in validating fuel consumption data and operational efficiency for offshore vessels. The study is based on a typical offshore vessel operating in Brazilian waters, with a gross tonnage of 3,000 to 4,000 GT, the predominant range in the national offshore sector. The analysis includes detailed calculations of energy efficiency, average engine loads, and specific emissions, considering different operational modes, such as DP and navigation.

This work also addresses the gap in the literature regarding the analysis of indicators for offshore vessels, which are often excluded from global regulations. Through a review of current practices and the introduction of new approaches, this study contributes to advancing the maritime sector toward a more sustainable future, aligning with global decarbonization efforts and the IMO's climate goals.

HISTORICAL AND REGULATORY CONTEXT

The evolution of International Maritime Organization (IMO) regulations has aimed to promote practices that not only enhance safety in maritime operations but also reduce the sector's environmental impact. Since the implementation of Annex VI of the MARPOL Convention, which establishes limits for pollutant gas emissions from ships, the IMO has dedicated efforts to refining and expanding its guidelines to include new indicators and methods for calculating vessel energy efficiency [1,2,3,4,5].

For offshore support vessels, which play a vital role in offshore operations, applying IMO standards presents unique challenges. These vessels, often equipped with diesel-electric propulsion systems and Dynamic Positioning (DP) systems, have distinct operational profiles compared to coastal and seagoing ships. Energy efficiency, traditionally calculated based on the ratio of fuel consumption to distance traveled combined with cargo capacity, does not directly apply to vessels whose primary contribution occurs while under DP, maintaining a “static” position during critical operations [6,7,8].

Recognizing this distinction, the International Marine Contractors Association (IMCA) began developing specific indicators for offshore support vessels. In 2019, through the MEPC 74/6 document, two specific indicators were proposed: Proxy A and Proxy B [6,7].

Proxy A is based on the vessel’s annual energy consumption, adopting a more conservative and linear approach over time. This indicator, studied in the report “Energy

Efficiency: What Does the Offshore Support Sector Have to Do with It?" where Brazil's profile was calculated against Proxies A and B, showed that Proxy A tends to exhibit smaller variations over the years, reflecting a more stable efficiency strategy. Conversely, Proxy A, as observed in formula 2, considers the engine runtime, assuming operation always at "Maximum Continuous Rated Power Output" (MCR). MCR is the maximum power of a marine diesel engine can continuously deliver without suffering damage or excessive wear. This power level, determined by the manufacturer, is considered safe for continuous engine operation under normal conditions. In other words, it is the maximum energy capacity the engine can generate without compromising its integrity or lifespan [6,7].

The GHG Fuel Indicator (GFI), represented by formula 3, stems from the IMO Guidelines on Life Cycle GHG Intensity of Marine Fuels. This resolution, known as the LCA Guidelines, measures the emissions intensity associated with fuel consumption, providing a direct metric of vessels' contribution to greenhouse gas emissions [1,2,4].

Additionally, Brazil developed the Energy Operational Index (EOI), represented by formula 2, which was submitted to the IMO on August 9, 2024, and will soon be accessible via IMO Docs (the IMO's official document access system). The EOI aims to be a voluntary adoption validation mechanism that considers not only fuel consumption but also variations in energy usage during operations. Through its synergy with the GFI, it can become a comparative validation mechanism to verify the consumption parameters used in the GFI [10].

The application of indicators for offshore support vessels, as described in MEPC 304, is part of the short-term measures prioritized by the IMO to improve energy efficiency and reduce greenhouse gas emissions. However, one of the greatest challenges faced by the IMO is defining what constitutes energy efficiency for vessels with unconventional propulsion systems, such as diesel-electric propulsion, which is prevalent among dynamic positioning ships [8].

Analyzing the impact of IMO regulations on the energy efficiency of these vessels makes it evident that the traditional mathematical model, based on displacement and cargo capacity, needs to be adapted to reflect the operational realities of offshore support vessels. The development of specific proxies, such as Proxy A and Proxy B, alongside the use of the GFI and EOI, represents a significant step forward in this direction, offering more suitable parameters for measuring and improving the energy performance of these vessels in a complex and dynamic operational context.

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CALCULATION FORMULAS FOR THE INDICATORS

It is important to highlight that all the indicators discussed in this study align with the European strategy, focusing on the relationship between GHG (Greenhouse Gas) emissions and the energy consumed by the vessel. The main difference between the indicators lies in their approaches: the EOI uses the actual power in each operational mode, providing a more accurate assessment adapted to real conditions. Proxy A, on the other hand, is based on the MCR (Maximum Continuous Rating) power, a fixed and conservative value that, while safe, does not reflect operational reality, as the vessel does not operate at this maximum power 100% of the time. Meanwhile, the GFI Target (GHG Fuel Indicator Target) considers only fuel consumption, directly disregarding the power used, addressing it indirectly through the consumption factor.

1. EOI (Operational Efficiency Indicator): The EOI is a validation mechanism designed to measure the actual operational efficiency of a vessel by accounting for power variations in different operational modes. This dynamic approach provides more accurate and effective results for energy efficiency across the ship's various daily operational modes. The concept of the EOI expression is similar to the GFI and derived from Proxy A.

Its calculation is based on the formula:

$$\frac{\text{Fuel consumption in grams} \times \text{carbon factor}}{\Sigma \text{ Average real power for each operational mode x hours corresponding to each mode}} \quad (1)$$

The formula 1 considers the peculiarities of operational modes, offering a detailed and realistic assessment of the vessel's energy efficiency and resulting emissions. The selected operational modes are DP operations, anchored, standby, navigating, and docked.

2. Proxy A (Design Efficiency Indicator): Proxy A, as defined by the International Marine Contractors Association (IMCA), is an indicator that evaluates energy efficiency based on the ship's design parameters. This approach is based on the engines' nominal power, and its calculation reflects actual fuel consumption, resulting in a static view of energy efficiency.

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$$\frac{\text{Fuel consumption in grams} \times \text{carbon factor}}{\Sigma \text{ Power at MCR of each engine x hours}} \quad (2)$$

The proxy A, in formula 2, exhibits an exponential behavior curve, with more pronounced variations over the years.

This indicator provides a broad view of energy efficiency, considering the vessel's total operations over a year. Unlike the EOI, which assesses efficiency at an operational level, Proxy A offers a more global and less detailed perspective on the ship's annual operations.

3. GHG Fuel Indicator (GFI)/Taget: The GFI measures the emission intensity associated with fuel consumption (g CO_2e/MJ).

$$\frac{\text{Fuel consumption in grams} \times \text{carbon factor}}{\text{Unit of energy used onboard}} \quad (3)$$

The formula 3, provides a direct metric of the vessel's contribution to greenhouse gas emissions.

Despite differences in formulas and approaches to measuring energy efficiency, Proxy A, EOI, and GFI share several similarities:

1. Focus on Fuel Consumption: All indicators use fuel consumption as a central variable, quantifying the amount of fuel consumed;
2. Incorporation of the Carbon Factor: All formulas include the carbon factor, which converts fuel consumption into CO_2eq emissions. This factor is crucial for determining the environmental impact of fuel consumption per energy unit.;
3. Measurement of Power: Both Proxy A and EOI use engine power as a key variable. Proxy A considers the engines' nominal power (MCR), while EOI uses the average real power across different operational modes;
4. Consideration of Time: Both Proxy A and EOI integrate the time factor. In Proxy A, time is reflected in the engines' operating hours. In EOI, time is accounted for in each specific operational mode.

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ASPECTS RELATED TO OPERATIONAL MODES

Considering operational modes is essential for evaluating energy efficiency within the context of the operational safety of maritime vessels. Each operational mode, such as docked, anchored, standby, under DP (Dynamic Positioning), or navigating, has specific requirements that directly impact fuel consumption and resulting GHG emissions.

It is important to note that these operational modes mentioned in paragraph 9 are beyond the decision-making level of the vessel commanders as well as the companies to which they belong, as they comply with service contracts.

OPERATIONAL MODES AND PRE-DEFINED LAYOUTS

Vessels typically have pre-defined layouts for each operational mode, which include the condition of the engine room. These layouts consider various factors, ranging from the number of engines in line to the power available for each operational mode, as well as the addition of more engines to meet additional energy needs. These demands may be required when specific equipment is in use or when environmental conditions pose a threat to the operation.

For example, during DP mode operations, where positioning accuracy is crucial, the energy demand is significantly higher. To ensure the vessel remains stable, it may be necessary to use more engines or increase the power available on the engines in operation. These adjustments ensure safe and efficient operations, minimizing risks from failures and optimizing fuel consumption.

OPERATIONAL MODES IN ENERGY EFFICIENCY CALCULATION

The consumption arising from operational modes can contribute to the calculation of energy efficiency by considering the real average consumption of each situation, instead of the MCR (Maximum Continuous Rating) used in Proxy A.

The EOI provides a more realistic computation of fuel consumption, reflecting the actual operational conditions of the vessel, rather than adopting a fixed consumption at a certain power level as used in the calculation of EEDI (Energy Efficiency Design Index) and EEXI (Energy Efficiency Existing Ship Index).

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OBJECTIVE OF THE STUDY

The objective of this study is to analyze and compare the energy efficiency and greenhouse gas (GHG) emissions of offshore support vessels through a case study of two active vessels in offshore support, using three different indicators: the Energy Operational Index (EOI), Proxy A, and the GHG Fuel Indicator (GFI). This study aims to understand how each indicator reflects the operational reality of offshore vessels, considering the real power used in different operational modes, the impact of maximum continuous rated power (MCR), and fuel consumption.

Additionally, the study aims to validate the applicability of the EOI as a more accurate metric adapted to the real operational conditions of offshore support vessels, especially in the context of the Brazilian proposal to the International Maritime Organization (IMO). By comparing the results obtained with the established indicators, the goal is to demonstrate the effectiveness of the EOI in providing a more detailed assessment of the energy efficiency and environmental impact of vessels.

METHODOLOGY

To assess operational efficiency and the effectiveness of the Energy Operational Index (EOI) as a validation mechanism, a detailed analysis was conducted on the operational and fuel consumption data of a PSV (Platform Supply Vessel).

The analyzed data was reported to the flag through the Data Collection System (DCS) and supplemented with a triangulation of information from different sources, including estimates based on the Bunker Delivery Note (BDN), measurements from flow meters, engines power register software, and calculations based on the effective work of the engines.

CASE STUDY — OPERATIONAL EFFICIENCY ANALYSIS OF AN OFFSHORE VESSEL

This case study examines an Offshore Support Vessel (PSV — Platform Supply Vessel) operating in the offshore sector. The analysis focuses on evaluating operational efficiency and the effectiveness of the Energy Operational Index (EOI) validation mechanism for fuel consumption data, which is used to develop the GHG Fuel Indicator (GFI) target. The vessel in question represents a typical offshore operation, with data reported and collected from various sources, providing a comprehensive view of energy consumption practices and the variables involved in the energy efficiency analysis.

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VESSEL CHARACTERISTICS

The vessel in question is classified as a PSV (Platform Supply Vessel), primarily used for logistical support to oil platforms. This type of vessel is considered predominant in the Brazilian offshore sector, according to reports from the Brazilian Association of Maritime Support Companies (ABEAM), both by type and by gross tonnage, being widely used in support operations. The technical specifications include:

- Vessel Type: PSV (Platform Supply Vessel)
- DP Class: 2 (Dynamic Positioning Class 2)
- Gross Tonnage: 3,933
- DWT (Deadweight Tonnage): 4,700

These characteristics represent a typical offshore support vessel, operating in challenging environments that require high-energy efficiency and precision in maneuvers, especially in dynamic positioning (DP) operations.

OPERATIONAL AND TECHNICAL DATA

For the analysis, detailed data was collected from the main engines of the vessel, which play a critical role in its operational efficiency. The vessel is equipped with four diesel engines, brand Caterpillar, four stroke, model 3512. The main specifications of the engines include:

- Nominal Power: 1,630 kW per engine
- Design-Specific Fuel Consumption: 200 g/kWh
- Main Fuel Type: MGO (Marine Gas Oil)

Additionally, operational data for each engine was obtained regarding the most common modes of operation, including DP operations, navigation, maneuvering, anchoring, and port operations. The collected metrics cover:

- Annual Average and Specific Power per Mode of Operation: Energy consumption in each mode, in kWh;
- Operating Hours per Mode of Operation: Annual average of operating hours, including specific data for DP, navigation, maneuvering, anchoring, and port;
- Total Hour Meter: Records the total accumulated operating time for each engine.

The data collection included self-declared fuel consumption sources, such as flow meters installed on the vessel, and supplementary information from the Bunker Delivery Note (BDN). Despite the usefulness of these sources, it is emphasized that limitations in the precision of engine-specific fuel consumption control may lead to discrepancies, highlighting the importance of robust validation mechanisms like the EOI.

IMPORTANCE OF THE STUDY

The analysis of this offshore vessel, representative of the maritime support segment in Brazil, holds strategic importance for understanding the operational challenges faced by PSVs (Platform Supply Vessels). These vessels, predominant in the Brazilian offshore sector, play a crucial role in logistical support operations, especially in scenarios that demand high-energy efficiency and precision, such as in dynamic positioning (DP). The growing regulatory and environmental pressure imposed by the International Maritime Organization (IMO) requires shipowners and operators to navigate a complex landscape of energy efficiency indicators and greenhouse gas (GHG) emissions management. In this context, the need for reliable data becomes essential for making technical and policy decisions.

RESEARCH QUESTION

This study seeks to answer the following key question: “Is the Energy Operational Index (EOI) more effective and accurate as a mechanism for validating fuel consumption data for offshore support vessels, compared to Proxy A, and how can it contribute to the development of the GHG Fuel Indicator (GFI) target proposed by the IMO?”

HYPOTHESES

Based on the data collected in vessel, technical literature, and sector reports, the following hypotheses are proposed for analysis:

Hypothesis 1: The EOI is more effective than Proxy A because it considers power variations in different operational modes, offering a more dynamic assessment aligned with the actual operating conditions of offshore support vessels.

Hypothesis 2: Proxy A, despite being widely used, has limitations due to its static approach based on the MCR (Maximum Continuous Rating) of the engines, making it less representative for offshore vessels that operate in multiple power and maneuver modes.

Hypothesis 3: Traditional fuel consumption estimation methods, such as the Bunker Delivery Note (BDN), are insufficient for accurately measuring actual fuel

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consumption due to the lack of engine-specific control and the difficulty in distinguishing fuel actually burned from the total onboard fuel.

Hypothesis 4: The adoption of EOI as a validation mechanism is particularly advantageous for vessels that lack indicators such as the EEDI (Energy Efficiency Design Index) or EEXI (Energy Efficiency Existing Ship Index), especially in the offshore support sector, where vessels typically have high operational dynamics.

STRATEGIC AND ACADEMIC RELEVANCE

This study is relevant not only for the technical analysis of the EOI and Proxy A, but also for its practical application in a critical sector like the Brazilian offshore industry. It addresses the gap in data validation methods for vessels without energy efficiency design indicators (EEDI) or energy efficiency existing indicators (EEXI). The reliability of fuel consumption data is essential for setting realistic targets in the GFI target, and the accuracy of validation mechanisms directly impacts global maritime decarbonization efforts.

Furthermore, by investigating the EOI as a validation tool, this work contributes to the development of more effective policies and practices, strengthening Brazil's role in international discussions on energy efficiency and sustainability in maritime transport. Finally, by exploring the limitations of Proxy A and traditional metrics such as the BDN, the study promotes critical reflection on the challenges and opportunities for improving energy management in the sector.

DATA COLLECTION AND PROCESSING

DATA COLLECTION STRATEGY

The data collection for this study was based on information voluntarily provided by the shipowner through the Brazilian Association of Maritime Support Vessel (ABEAM). The analyzed data corresponds to a real vessel operating in Brazilian waters, characterized by a tropical environment with specific challenges for energy efficiency. For confidentiality reasons, the vessel's name was not disclosed. However, its operations reflect the typical conditions faced by PSVs in the national offshore sector.

DATA TRIANGULATION

To ensure the accuracy of the analysis, data triangulation was performed using information about:

- Average Annual Power of Engines in Each Mode of Operation: Data on the average engine power were obtained and analyzed for the main modes of operation: DP (Dynamic Positioning), navigation, maneuvering, anchoring, and port operations. This metric was essential for calculating the actual energy consumption associated with each mode.
- Specific Consumption of Engines: The design-specific fuel consumption of the engines, measured in g/kWh, was used as a basis to determine the amount of fuel actually consumed.
- Operational Hours: The annual operating hours in each mode of operation were provided, enabling a detailed calculation of fuel consumption and efficiency in specific scenarios.

The data triangulation with the operational characteristics of the vessel's propulsion system brought greater accuracy to the analysis, allowing for a more robust and reliable assessment of operational efficiency and the effectiveness of the EOI as a validation mechanism.

TECHNICAL DATA OF THE VESSEL

The vessel analyzed in this study is a Platform Supply Vessel (PSV), whose propulsion is fully electric, utilizing azimuth thrusters instead of conventional rudders. This type of configuration is widely used in offshore support vessels, especially those designed for high maneuverability and precision in offshore operations.

The general data of the vessel analyzed, including key features, propulsion configurations, and operations in different modes, are presented in Table 1: Technical and Operational Specifications of the PSV Vessel. This table contextualizes the vessel as a representative unit of the Brazilian offshore sector.

Table 1: Technical and Operational Specifications of the PSV Vessel

Property	Value
Vessel Type	PSV

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Property	Value
DP Class	2
Gross Tonnage	3933
DWT	4700
Propulsion	Electric
Bus Configuration	Open (DP), Closed (other modes)
Nominal Voltage	6600V
DP Operation	Load on engines from 10% to 40%

Source: Author

The table provides an initial overview of the vessel's characteristics, serving as the basis for understanding the operational and technical data presented next.

DP CLASS AND DP OPERATION

The vessel is classified as Class 2, as defined by Resolution MSC/Circ.645 of the International Maritime Organization (IMO) and supplemented by Resolution IMO 1580. These resolutions establish the technical and safety criteria for Dynamic Positioning (DP) systems, categorizing vessels based on their redundancy levels:

- Class 1: System with minimum redundancy requirements, suitable for less critical operations.
- Class 2: System with sufficient redundancy to support the failure of any active component without compromising the operation. It is suitable for operations where the loss of position could cause significant damage to the environment or equipment.
- Class 3: System with complete redundancy, including compartmentalization and protection against fire and flooding, designed for high-criticality operations.

As a Class 2 vessel, the PSV analyzed is prepared for operations that require high precision and safety, such as oil platform support. It is designed to maintain its functions even if one of its active systems fails.

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DP OPERATION AND BUS CONFIGURATION

The vessel operates with a nominal voltage of 6,600V, a feature that favors energy efficiency by reducing electrical losses during power transmission and distribution.

- During DP operations, the system operates with an open bus configuration, meaning the generators are connected to independent systems. This configuration provides greater operational safety, ensuring that a failure in one bus does not compromise the entire system.
- In other modes of operation, such as navigation or anchoring, the vessel uses a closed bus configuration, allowing the interconnection of generators. This configuration enhances energy efficiency, optimizing load distribution and reducing specific fuel consumption.

TECHNICAL DATA OF THE ENGINES

The vessel's main engines were described and analyzed based on their technical specifications:

- Model: Caterpillar 3512
- Type: Diesel - 4 Stroke
- Nominal Power: 1,630 kW per engine
- Design-Specific Consumption: 200 g/kWh
- Fuel Type: MGO (Marine Gas Oil)
- Number of engines: 4

These engines play a critical role in the vessel's operations and were evaluated based on their performance in different modes of operation.

To complement the general information, Table 2: Technical and Operational Data of the Engines presents the details of the vessel's main engines. It includes information on power, specific consumption, modes of operation, and operating hours, which are essential for the energy efficiency analyzes.

Table 2: Technical and Operational Data of the Engines

PSV / Class 2 / GT 3933				
Equipment: Diesel Generator	Dg1	Dg2	Dg3	Dg4
Diesel or Electric	Diesel	Diesel	Diesel	Diesel

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Type (2 stroke or 4 stroke)	4 stroke	4 stroke	4 stroke	4 stroke
Brand	Caterpillar	Caterpillar	Caterpillar	Caterpillar
Model	3512,00	3512,00	3512,00	3512,00
Main Fuel Type	MGO	MGO	MGO	MGO
Power (kW)	1630,00	1630,00	1630,00	1630,00
Specific Design Consumption (g/kWh)	200,00	200,00	200,00	200,00
Annual Average Power (kWh)	371,44	251,69	382,71	223,92
Power in DP Operation (kWh)	310,00	310,00	310,00	310,00
Power in Navigation (kWh/year)	1119,13	754,68	1151,01	725,89
Power on Tacking (kWh/year)	283,55	187,85	270,99	125,4
Power in Port (kWh/year)	23,01	23,01	23,01	23,01
Power at Anchor (kWh/year)	60,07	41,23	42,93	21,38
Average Annual Operating Hours (h)	4424	3196	4301	2671
Hours in DP Operation (h)	568	568	568	568
Hours in Navigation (h)	1695	1143	1749	1103
Hours Tacking (h)	1671	1107	1597	739
Hours at Anchor (h)	354	243	253	126
Hours in Port (h)	136,00	135,00	134,00	135,00
Hour Meter (h)	30810	14548	29297	27863

Source: Author

This table details the performance of the vessel's engines in each mode of operation, complementing the general information presented in Table 1. The collected and processed data form the basis for the energy efficiency analyses and fuel consumption validation that will be discussed in the subsequent chapters.

LOW LOAD OPERATION

In general, during DP operations of Offshore Supply Vessel (OSV), to keep the power reserve and spinning ruining reserve of energy to fast response the environmental force. The vessel's engines responsible by generation of energy of ship operate with significantly reduced loads, typically between 10% and 40% of the nominal load.

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This characteristic is typical for offshore support vessels, as the DP system only consumes the energy necessary to counterbalance external forces such as wind, current, and waves, rather than operating at full capacity.

Although this low-load operation is sufficient to maintain the vessel's position, it presents a challenge for energy efficiency analysis, as the engines generally operate outside their most efficient points. This behavior reinforces the importance of using validation mechanisms, such as the Energy Operational Index (EOI), that consider the real operating conditions and the specificities of vessels of this type.

PROPULSION SETUP

The vessel is equipped with azimuth thrusters, which replace conventional rudders and offer greater flexibility and precision in maneuvering. This configuration, combined with electric propulsion, provides advanced control over the power distribution between the engines and propulsion systems, enabling greater energy efficiency in different operational modes.

DATA PROCESSING

Data processing followed a structured methodology, with an emphasis on correcting discrepancies and ensuring the reliability of the analyses:

- Error Correction and Data Consistency: The combination of average annual power, specific fuel consumption, and operating hours allowed for adjustments to the initial fuel consumption estimates, correcting discrepancies observed in the reported data.
- Calculation of Energy Actually Used: The energy actually used by the engines was calculated by considering the product of the mass of fuel consumed and the lower calorific value (LCV) of the fuel, adjusted to reflect the average annual power in each operational mode.
- Segmentation by Operational Mode: The data was stratified by each operational mode, allowing specific and detailed analyses, which are fundamental to understanding the vessel's performance in different scenarios.

Application of the Energy Operational Index (EOI): The EOI was calculated based on the effective energy used by the engines as the denominator and CO_2 equivalent emissions

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as the numerator. This metric was used to validate fuel consumption data, highlighting its usefulness as an analytical tool.

IMPORTANCE OF OPERATIONAL CONTEXT

The vessel operates in tropical waters, where factors such as high temperatures, salinity variations, and weather conditions can significantly impact energy efficiency and fuel consumption. These conditions reinforce the relevance of a detailed study that considers the specific challenges faced in Brazilian maritime operations.

METHODOLOGY OF CALCULATION

Operational efficiency was analyzed based on the following parameters:

1. Fuel consumption (mass, in tons): Related to the available energy of the fuel, calculated by the lower calorific value (LCV) of the type of fuel oil used.
2. Effective energy (Energy Total): Represents the energy that was effectively transformed into work by the engines.
3. Energy Operational Index (EOI): Was calculated by considering the effective energy used in the engines as the denominator and the total CO_2 equivalent emissions as the numerator, in gCO_2eq/MJ.

The calculations were performed for different operational modes of the vessel, including DP (Dynamic Positioning), navigation, maneuvering, anchoring, and port operations.

The calculation methodology was developed to assess the vessel's operational efficiency. It validated the use of the Energy Operational Index (EOI) as a more accurate and effective mechanism compared to Proxy A, especially for offshore support vessels operating under dynamic and variable conditions. This approach allowed for investigating how energy consumption and emissions data align with the proposed hypotheses, highlighting the advantages of the EOI.

STEPS OF THE METHODOLOGY

The methodology was based on three main steps, each directly linked to the formulated hypotheses:

1. Calculation of the Effective Energy Used in the Engines The first step consisted of calculating the effective energy transformed into work by the engines,

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considering the average annual power in each operational mode. For this, the following equation was used:

Effective Energy (MJ) = Fuel Consumption (ton) × LCV (MJ/ton) (4)

Where:

a. Fuel Consumption was obtained through triangulation, considering the average power, the specific fuel consumption of the engines (200 g/kWh), and the annual operating hours.
b. LCV (Lower Calorific Value) was fixed at 42,700 MJ/ton, representing the lower calorific value of MGO.

This step provides the basis for accurate energy efficiency analysis and is directly linked to Hypothesis 1, which postulates that the EOI, by incorporating these real operational variables, is more accurate than Proxy A, which uses only static data.

2. Calculation of Total Fuel Energy Total Fuel Energy was obtained by multiplying fuel consumption by the calorific value of the fuel. For this, the following equation 5 was used:

Total Energy = Fuel Consumption (ton) × LCV (42,700 MJ/ton) (5)

3. Calculation of the Energy Operational Index (EOI)
   The EOI was calculated as (formula 6) :

EOI(gCO2eq/MJ) = CO_2 equivalent emissions / Effective Energy Used (6)

Where:

a. CO_2 equivalent emissions were calculated based on the reported fuel consumption and standard emission factors.
b. Effective Energy Used is the energy calculated in the previous step.

The EOI was compared to Proxy A value, which uses the MCR (Maximum Continuous Rating) as a reference to determine efficiency. This step is connected to Hypothesis 2, which states that Proxy A has limitations by disregarding dynamic load variations.

4. Analysis of Engine Load Variations by Operational Mode The third step assessed the average loads of the engines in different operational modes (DP, navigation, maneuvering, port, and anchoring). The following formula 7 was used:

Average Load (%) = Average Power (kW)×100 / Nominal Power (kW) (7)

This analysis allowed for the identification of underutilization patterns (10% to 40% of capacity) in DP operations, aligning with Hypothesis 4, which postulates that the

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EOI is more suitable for validating fuel consumption data of vessels operating in multiple dynamic modes.

RESULTS

This section presents the results of the calculations performed to assess the operational efficiency of the vessel and validate the Energy Operational Index (EOI) compared to Proxy A, highlighting the differences between the two mechanisms. The data were quantified and organized into tables to detail the obtained values, allowing for a robust analysis of the indicators.

COMPARISON BETWEEN EOI AND PROXY A

The calculation of Proxy A is based on a static approach, considering the Maximum Continuous Rating (MCR) of the main engines, without accounting for dynamic load variations or different operational modes.

The values calculated for Proxy A were compared to those of the EOI, detailed in Table 3: Comparison between EOI and Proxy A by Operational Mode.

Table 3: Comparison between EOI and Proxy A by Operational Mode

Operational Mode	Fuel Consumption (ton)	Effective Energy (MJ)	EI (gCO_2eq/MJ)	Proxy A (gCO_2eq/MCR)
DP	409,30	2.535.552,00	13,63	18,45
Navigation	795,08	20.063.871,90	55,51	61,90
Drifting	532,96	4.345.933,07	17,94	22,12
Berthed	97,28	423.623,30	9,58	12,35
Anchored	90,89	80.847,94	1,96	2,50
Total	1.925,50	27.449.828,21	31,4	39,5

Source: Author

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Table 3 presents a direct comparison between the values obtained by the EOI and Proxy A, highlighting the main differences between the two validation mechanisms. It is organized as follows:

- Fuel Consumption (ton): The total amount of fuel consumed in each operational mode.
- Effective Energy (MJ): The energy that was effectively converted into work by the engines.
- EI (gCO_2eq/MJ): The specific emissions calculated by the EOI, reflecting the real operational conditions.
- Proxy A (gCO_2eq/MCR): The specific emissions calculated based on the MCR and operational hours, representing the static approach of Proxy A.

RESULTS ANALYSIS

The calculations performed highlighted significant differences between the EOI and Proxy A, demonstrating the superiority of the EOI in evaluating energy efficiency and validating fuel consumption.

The EOI showed lower and more consistent specific emissions across all operational modes, proving its ability to reflect the real conditions of the vessel. On the other hand, Proxy A, which depends on the MCR (Maximum Continuous Rating), overestimated emissions by not considering the dynamic load variations, especially in scenarios with low-energy demand.

DYNAMIC POSITIONING OPERATION (DP)

In this study, the calculations revealed that, for the analyzed vessel, the average load in DP mode was approximately 19%, positioning it at the lower end of the expected range. This means that, in practice, the vessel's engines operated with loads below what would be required to achieve ideal energy efficiency. In comparative terms, the calculated efficiency for DP was only 14.51%, indicating that most of the potential energy from the fuel consumed was not converted into useful work.

The EOI captured the operational efficiency in this scenario with greater accuracy, resulting in specific emissions of 13.63 gCO_2eq/MJ. In contrast, Proxy A, disregarding the low actual load of the engines, presented an inflated value of 18.45 gCO_2eq/MCR, highlighting its limitation in dynamic operational contexts.

NAVIGATION

During navigation, the increase in the average load of the engines improved operational efficiency, a fact well reflected by the EOI, which calculated specific emissions of 55.51 gCO_2eq/MJ. Proxy A, however, resulted in 61.90 gCO_2eq/MCR, demonstrating an overestimation of emissions in this mode, even though the engines were operating closer to their ideal conditions.

BERTHED AND ANCHORED

In the berthed and anchored modes, characterized by very low loads when compare with other models, the EOI again demonstrated greater sensitivity to real conditions. Proxy A, with its static approach, continued to overestimate emissions, reinforcing its inadequacy for representing these low-demand operations.

TOTAL RESULTS

In the total calculation, the EOI presented a global value of 31.4 gCO_2eq/MJ, while Proxy A provided 39.5 gCO_2eq/MCR, a discrepancy that reflects the greater accuracy of the EOI by integrating dynamic operation data. Furthermore, the triangulation of the data revealed that the reported fuel consumption to the flag (680.80 tons) underestimated the actual consumption, which totaled 1,925.50 tons. This difference was corrected by the EOI, confirming its effectiveness in validating inconsistent data.

ADAPTATION TO OPERATIONAL VARIATIONS

Table 3 illustrates how the EOI adapts to the vessel's different operational conditions, reflecting the nuances of each mode with greater fidelity. In contrast, Proxy A provides static, less representative values and fails to capture the peculiarities of scenarios such as DP or anchoring.

These results reinforce the applicability of the EOI as a robust validation mechanism, particularly in the context of developing the GHG Fuel Indicator (GFI) target, promoting more accurate analyses aligned with the maritime sector's operational realities.

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AVERAGE ENGINE LOAD ACROSS DIFFERENT OPERATIONAL MODES

The analysis of average engine load in the various operational modes highlighted significant contrasts between Dynamic Positioning (DP) mode and Navigation mode, the two most relevant scenarios for evaluating the vessel's operational efficiency.

The DP (Dynamic Positioning) mode demonstrates an operational pattern typical of maritime support vessels, characterized by low engine loads, usually ranging between 10% and 40% of their nominal capacity in offshore sector vessels. This range reflects what is commonly observed in ships during similar operations, as the DP system consumes only the energy necessary to counterbalance external forces, such as wind, currents, and waves, without requiring full engine power. However, these low-load conditions can compromise energy efficiency, as engines operate outside their optimal performance points.

In DP mode, the engines operate at an average load of approximately 19%, significantly below the ideal energy efficiency range, generally between 70% and 85% of nominal load. This characteristic is intrinsic to dynamic positioning operations, where the energy consumed is used to counterbalance external forces (wind, currents, and waves), keeping the vessel static relative to a specific point. While this demand is essential for the safety and functionality of the vessel in DP mode, it results in significant inefficiencies, as evidenced by the calculated energy efficiency of 14.51% for this mode. This occurs because engines operating at low load exhibit higher specific fuel consumption (g/kWh), leading to greater energy loss.

Conversely, Navigation mode exhibited an average load of 68.66%, close to the engines' optimal operational range. This proximity reflects the stability of the energy consumption required for the vessel's continuous movement, where the main propulsion operates more efficiently. As a result, although fuel consumption in this mode is the highest among all scenarios analyzed (795.08 tons), the energy yield is considerably better, allowing for a more effective transformation of the fuel's potential energy into useful work. This superior efficiency in Navigation mode illustrates the positive impact of operating engines in optimized load ranges.

The comparison between these two modes reveals an operational dilemma: while DP mode is essential to perform critical functions in the offshore sector, it inevitably results in inefficiencies due to low load. Navigation mode, on the other hand, although requiring higher absolute fuel consumption, demonstrates how increasing engine load can improve relative efficiency. This distinction underscores the importance of mechanisms such as the

Energy Operational Index (EOI), which capture these operational nuances and provide an accurate assessment of energy efficiency under real usage conditions.

FINAL CONSIDERATIONS

The results of this study consolidate the relevance of the Energy Operational Index (EOI) as a validation mechanism for analyzing energy efficiency in maritime support vessels. Through its dynamic approach, which considers actual operating conditions, the EOI proved to be more accurate and reliable compared to Proxy A and traditional methods such as the Bunker Delivery Note (BDN). These characteristics make the EOI an essential tool for validating fuel consumption data used in the composition of the GHG Fuel Indicator (GFI) target, contributing to the development of more realistic and industry-aligned goals.

The analysis highlighted the importance of adopting specific strategies to optimize operations in low-load modes, such as Dynamic Positioning (DP). In these scenarios, the EOI revealed the energy inefficiency caused by average loads of only 19%, indicating the need for load redistribution or adjustments in power control to reduce environmental impact. On the other hand, Navigation mode, with an average load of 68.66%, proved to be the most efficient, demonstrating how operating in optimal load ranges can maximize energy yield. This understanding is crucial to guide technical and operational decisions aimed at sustainability in the offshore sector.

The results refuted the applicability of Proxy A as a validation mechanism for maritime support vessels, particularly due to its reliance on static parameters such as MCR (Maximum Continuous Rating), which fail to capture the nuances of dynamic operational modes. In contrast, the EOI corrected discrepancies observed between the reported fuel consumption and the actual consumption, revealing an underestimation of 680.80 tons in the declared consumption. This adjustment directly evidences the EOI's ability to provide more accurate and reliable analyses.

CONCLUSION

This study evaluated the energy efficiency and greenhouse gas (GHG) emissions of maritime support vessels, focusing on the comparison between the validation mechanisms Proxy A and Energy Operational Index (EOI) in the context of the GHG Fuel Indicator (GFI) target. The analysis confirmed that for vessels not subject to indicators such as the Energy

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Efficiency Design Index (EEDI) or the Energy Efficiency Existing Ship Index (EEXI), the EOI is a superior mechanism capable of more accurately capturing actual operating conditions.

The EOI stood out by integrating power variations across different operational modes, better reflecting the complexity and peculiarities of the offshore sector. This dynamic approach contrasted with Proxy A, whose dependence on static parameters resulted in overestimated emissions and reduced reliability.

The adoption of the EOI as a validation tool in the development of the GFI target represents a significant advancement for the maritime sector. In addition to promoting greater accuracy in GHG emissions management, the EOI provides a robust foundation for implementing more efficient and sustainable operational practices. Applying this mechanism reinforces the importance of considering the operational specificities of maritime support vessels, aligning with global decarbonization goals and the sector's commitment to sustainability.

These conclusions reaffirm the strategic role of the EOI in transitioning to more efficient and environmentally responsible maritime transport, highlighting its potential as a global benchmark for data validation in the context of climate change.

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