Carbon Intensity Indicator (CII) Calculation Analysis For Operational Feasibility of Passenger Ships

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Abstract.

The Maritime industry faces increasing pressure to reduce greenhouse gas emissions under the International Maritime Organization's Carbon Intensity Indicator (CII) framework. This study evaluates operational performance, fuel consumption, and carbon intensity for two aging passenger ships operated by PT. XYZ (Passenger Ship A, 34 years; Passenger Ship B, 33 years) and assesses whether repowering can improve efficiency and compliance. Financial feasibility is projected using trendline regression under two scenarios: without subsidies and with subsidies. Results indicate that without subsidies, both ships are projected to incur losses from the initial period, with deficits increasing annually. Under subsidies, Passenger Ship A's gross profit is projected to become negative starting in 2028, while Passenger Ship B is expected to remain financially positive. Environmentally, CII results show rising carbon emission intensity, averaging annual increases of 0.56% for Passenger Ship A and 2.09% for Passenger Ship B, leading to declining CII ratings over time. Passenger Ship A is projected to reach Rating E during 2029–2035, requiring a critical operational decision by 2031, while Passenger Ship B is projected to reach Rating E during 2031–2035, requiring a decision by 2033. Repowering reduces annual fuel consumption by 41.4% and 47.5%, respectively, and improves both ships' CII ratings to Rating A, supporting continued operation with international environmental compliance.

Keywords: *CII Rating; Emission; Fuel; Repowering; Vessel Age and Passengers Ships.*

I. INTRODUCTION

As industrialization has expanded since the Industrial Revolution, human activities have generated significant environmental impacts, including climate change. Climate change refers to long-term and significant changes in the average climate state or its variability, including temperature, precipitation patterns, sea level, and the frequency of extreme weather events [1]. The Paris Agreement aims to limit global warming to well below 2°C above pre-industrial levels, with efforts to keep it below 1.5°C. Many countries have set net zero emission (NZE) targets for 2050. In line with these commitments, through its Nationally Determined Contribution (NDC), Indonesia targets a 31.89% emissions reduction by 2030 and NZE by 2060 by balancing greenhouse gas emissions with removals by carbon sinks [2]. Although maritime transport contributes to greenhouse gas emissions, emissions from the shipping sector are often underestimated. This is partly because maritime transport is considered the most energy-efficient mode of transportation, in terms of energy required to move one ton of cargo over one kilometer (per ton-km). However, ship operations still involve fuel combustion processes in the main engine, auxiliary engines, and boilers [3]. These combustion activities release not only greenhouse gas emissions such as CO_2 but also other pollutants that can intensify environmental impacts, including NOx, SOx, and particulate matter (PM) [4]. As an archipelagic country, Indonesia relies heavily on maritime transportation to support regional connectivity, reduce price disparities between regions, and improve national logistics efficiency.

With increasing growth in maritime activities, emissions from this sector are projected to rise, posing challenges for national decarbonization efforts. As part of the decarbonization strategy, effective indicators are required to continuously monitor and evaluate ships' emission performance. One instrument currently applied to measure and control carbon emissions from ships is the Carbon Intensity Indicator (CII). CII is a key indicator for assessing the operational efficiency of commercial ships by reflecting the amount of carbon intensity generated per cargo unit and distance travelled. Its importance has increased since the implementation of international regulations requiring ships, starting from 1 January 2023, to collect and document relevant operational data for CII calculation. CII ratings range from A (best performance) to E (worst performance) and are designed to encourage CO_2 emission reduction and continuous improvement in operational efficiency. This regulation demonstrates a strong commitment from the international maritime community to guide the shipping industry toward more environmentally sustainable operations.From an operator's perspective, especially for aging fleets, CII projection plays a critical role in strategic decision-making.

Estimating future CII values enables operators to assess operational feasibility, identify required performance improvement measures (e.g., technological upgrades or operational strategies), and consider fleet management decisions such as early retirement or scrapping. In addition, CII projection supports investment planning, including the transition toward lower-emission fuels and technologies.However, current studies remain limited in comprehensively integrating CII projections with operational feasibility indicators. Most previous research emphasizes CII calculations under existing conditions, while fewer studies link future CII scenarios with their direct implications for operational decision-making. Therefore, research focusing on CII projection as an indicator for passenger ship operational feasibility in future periods remains highly relevant, particularly under increasingly stringent environmental regulations.

II. METHODS

A. Previous Research

Prior studies indicate that Carbon Intensity Indicator (CII) performance is highly sensitive to operational practices and environmental conditions and can be improved through targeted operational strategies. Garbatov & Georgiev demonstrated that voyage planning optimization through weather routing—accounting for wind, waves, and currents—can significantly reduce carbon intensity and improve operational efficiency [5]. From a governance perspective, Zulfiqar & Chang positioned CII as a core IMO mechanism for carbon intensity control, closely linked to energy-efficiency requirements such as EEXI; thus, improving CII requires compliance with defined efficiency criteria [5].On operational mitigation, Maritime Faculty (Istanbul Technical University) & Zincir detailed the CII computation workflow (Required and Attained CII) and identified slow steaming as an effective measure to reduce fuel consumption and CO_2 emissions, thereby improving CII performance [6]. Beyond operational measures, Kanchiralla et al. assessed fossil-free fuel options using LCA and LCC and showed that techno-economic feasibility is strongly dependent on ship type and operational profile; some alternatives (e.g., methanol and ammonia in ICEs) can be more cost-competitive than battery-electric and fuel-cell options, which remain constrained by high upfront costs and onboard energy storage limitations [7] Overall, the literature highlights operational, regulatory, and technological pathways to improve CII. However, studies that link forward-looking CII projections to operational feasibility decision indicators, particularly for aging passenger vessels, remain limited motivating the present work to bridge environmental compliance with practical managerial and economic implications.

B. Basic concept of Emissions

Greenhouse gases are gaseous components in the atmosphere that absorb and emit radiation at specific wavelengths in the wave spectrum emitted by the earth's surface, atmosphere, and clouds. The nature of such greenhouse gases causes an effect called the greenhouse effect. Greenhouse gas emissions are mainly caused by anthropogenic activities such as the burning of fossil fuels, agriculture, and industrial processes [8]. The shipping sector contributed 2.89% of total anthropogenic emissions in 2018 [9]. In the reporting and comparison of emissions on a global scale, generally greenhouse gas emissions are written in CO2-equivalent units or CO2e. GHGs accumulated in the atmosphere form an overlay around the earth, resulting in the greenhouse effect. The greenhouse effect refers to the process that occurs when solar radiation in the form of visible light enters the atmosphere reaching the earth's surface and is absorbed, then emitted back in the form of long-wave infrared radiation. This process generates additional heat that makes the Earth's surface warmer. Under ideal conditions, the greenhouse effect is important for maintaining the Earth's temperature, but it is currently exacerbated by anthropogenic activity leading to global warming and climate change [10]. Components of greenhouse gases that naturally exist in the atmosphere include water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3). Meanwhile, greenhouse gases formed from anthropogenic activities include sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), and perfluorocarbons (PFCs) (IPCC, 2023). Of the several types of greenhouse gases, the main greenhouse gases that are a result of the fuel combustion process include carbon dioxide (CO_2), nitrogen oxide (N_2O), methane (CH_4).

C. Sources of Emissions in the Shipping Sector

Based on the classification of sources, emissions from the shipping sector can be divided into three sources, namely based on scope, by type of engine, and by the phase of shipping operations.Emission Sources Based on Scope are applied to determine emission sources more specifically so that there is no double calculation between two or more companies that calculate emissions in the same scope, such as between a power generation service provider and a service receiving company. Emission Sources By type of operational machinery Shipping operations include several types of systems, including main engines, auxiliary engines, and boilers. The operation of these three types of systems involves the process of burning fuel that produces emissions. The ship operation phase consists of three main operational activities, namely cruising, maneuvering, and hotelling. The three phases of operation have different characteristics, including differences in the type of engine operated, the speed of the ship, the type of emissions, and the number of emissions caused.

D. Technical Parameter on ship Emission Calcualtion

Technical parameters regarding ship operations are used in the calculation of ship emissions based on activity. The technical parameters that need to be considered in the calculation of emissions are as follows.

1) Shipping Voyage

Shipping distance is the total amount of distance taken by a ship from the port of departure to the destination port, generally measured in nautical miles (nm) Shipping mileage is an important factor in the calculation of activity-based vehicle emissions because it directly affects the amount of fuel consumed so that it affects the emissions produced. In addition, in the context of emission studies, there is also a quantity called emission intensity, which is a measure of the number of emissions produced per unit of activity, or in the context of distance is per nautical miles traveled by ships ($kgCO_2/nm$) [11].

2) Ship Speed

Ship speed is a quantity that describes how fast the ship is traveling on water. Generally, this amount is measured in nautical miles per hour (knots). The speed of a ship is important to know in the calculation of emissions because the amount of fuel consumption in kilograms used per one nautical mile is determined based on the speed of the ship. Ship speed can be classified into two types of speed, namely service speed and actual speed. Design speed or service speed is the maximum speed standard for ships to operate under normal conditions. Meanwhile, actual speed is the amount of speed that the ship reaches during the voyage in real operational conditions. Generally, the actual speed value is different from the design speed because it is influenced by various factors including sea conditions, weather, and ship load factors during the voyage [12].

3) Duration of Machine Operating Time

The duration of engine operation time is defined as the duration when the ship's engine is active in operation throughout each phase of operation, starting from the sailing phase, namely cruising and maneuvering, to the leaning or hoteling phase. The difference in mileage and speed of the ship in each phase of operation makes the duration of operational time also different for each phase. Therefore, the amount of fuel consumption produced cannot be assumed to be the same for each phase of operation.

4) Revolutions Per Minute (RPM)

Engine Revolutions Per Minute (RPM) in the context of shipping is the number of revolutions of a ship's engine shaft that completes one full revolution in a one-minute time. This unit is used to determine the operational speed of the ship and the performance measure of the ship's propulsion system [13]. In general, increasing RPM can lead to higher fuel consumption as more power is needed to maintain higher revs [14]

5) Main Engine Power

Engine power is a significant factor in the calculation of emissions. The actual power of the main engine is influenced by various factors, including the type and size of the ship, the design and size of the propeller, as well as various operational conditions of the ship or sea conditions that affect the amount of power required [15]. In general, the actual power of the main engine is greatly influenced by the speed of the ship, where a decrease in the speed of the ship will result in less power requirement in the main engine [16]. The relationship between the two is nonlinear and under ideal conditions can correspond to the following equation of "Propeller Law"

$$P = k \times (RPM)^3 \quad (1)$$

Where:

P : engine power required (kW)

RPM : revolutions per minute (RPM)

k : Constant (based on the ship's technical design and sea conditions)

This equation shows the cubic relationship between speed and power. This means that when the RPM value is doubled, the power required will increase by eight times. Lower speeds will result in lower power requirements, resulting in a reduction in fuel consumption [17].

6) Specific Oil Fuel Consumption (SFOC)

Specific Fuel Consumption (SFOC) is a unit that expresses a measure of the fuel efficiency of an engine. Generally, SFOC values are expressed in grams of fuel consumed per kilowatt-hour of energy produced (g/kWh) [18]. A lower SFOC value indicates high engine efficiency as less fuel is required to achieve the same engine power [19], [20]. There are several aspects that affect the value of SFOC, including engine load factors, fuel type and mixture, fuel quality, and engine mechanical conditions, including changes in engine speed and power.

7) Fuel Type

There are several types of fuel that are commonly used in cruise ship operations, including HFO, LNG, MDO, and Biodiesel. The type of fuel used in shipping determines the emission factors in the calculation of greenhouse gas emissions. The type of ship fuel used in Indonesia is in the form of biodiesel. Biodiesel is a type of renewable fuel that is made from a mixture of vegetable oils or animal fats. The type of biodiesel in Indonesia is generally in the form of fatty acid methyl esters (FAME) made from vegetable oil or animal fat that has gone through the esterification/transesterification process. Pure biodiesel containing 100% biodiesel is written as B100, where the number on the back indicates the percentage of FAME in the fuel mixture [21]

8) Emission Factors

Emission factors are the coefficient of emission measurement in units per unit of activity. This factor represents the average emissions or exhaust gases from a given activity in each set of operating conditions [22]. Emission factors link the activities that produce pollutants to the quantity of pollutants released into the atmosphere. This factor allows for estimating emissions from ships based on operational data so that it does not rely solely on direct emissions measurements [23]. In the context of shipping, the emission factor (EF) is usually written in terms of the number of pollutants produced per unit of engine energy (g/kWh), or per amount of fuel used (kg/kg fuel) [24]. One of the emission factors that can be used as a reference for the type of fuel in the form of biodiesel is the standard from the Environmental Protection Agency (EPA), where the amount of CO2 emission factor for combustion moving with pure biodiesel fuel (B100) is 9.45 kgCO2/gallon or around 2,496 kgCO2/liter. However, because there are differences in the type of vegetable oil in Indonesia with those used in the reference, as well as the lack of reference data from the Ministry of Energy and Mineral Resources for the type of biodiesel fuel, fuel characteristics tests can also be carried out in the laboratory to determine fuel characteristics such as emission factors and net calorific value (NCV).

9) Engine Fuel Consumption

Fuel consumption is the amount of fuel used by an engine to operate, generally measured in units of volume (kiloliters or m3). Fuel consumption is a determining factor in the calculation of household gas emissions from shipping activities because the fuel combustion process releases greenhouse gases (GHGs) in the form of CO_2 and several other types of pollutants that can worsen the greenhouse effect, including NO_x, SO_x, and PM [25].

10) Net Calorific Value (NCV)

Net Calorific Value (NCV) or also known as Lower Heating Value (LHV) is the specific amount of energy released per unit mass of fuel when fuel is burned in a condition of complete combustion with oxygen. This value does not consider the latent heat generated from the evaporation of water during combustion. This parameter is important in emission estimation because it shows the actual energy obtained and usable from the combustion of fuel.

11) Fuel Density

Density is a physical parameter for the mass of a substance per unit volume. Density is an important parameter that affects the operation of the fuel system. This value regulates how the engine burns fuel so that it affects the power produced, combustion efficiency, and affects the emissions produced [23]. In emissions calculations, generally density is used to convert large amounts of fuel consumption from units of volume (liters) to mass (grams). Through the Decree of the Director General of Oil and Gas of the Ministry of Energy and Mineral Resources Number 13483 K/24/DJM/2006, the standard specification of biodiesel biofuels for density parameters at 40oC temperature is 850-890 kg/m3.

E. Energy Efficiency Existing Index (EEXI)

As awareness of the impacts of climate change increases, international regulations related to the energy efficiency of ships are becoming increasingly important. The international shipping sector, which accounts for around 2.2% of total global CO_2 emissions, is expected to contribute to efforts to reduce greenhouse gas (GHG) emissions through the implementation of various regulations set by the International Maritime Organization (IMO). EEXI is an index introduced by the IMO to assess the technical energy efficiency of ships that are already in operation with the aim of reducing greenhouse gas emissions from the maritime sector. The EEXI regulation is contained in MARPOL Annex VI and explicitly only calculates CO_2 from the combustion of ship engines. This is confirmed in Resolutions MEPC.333 and MEPC.334(76) and is supported by the official IMO explanation that EEXI measures carbon intensities as CO_2 per ton-mile. Other greenhouse gases such as CH_4 or CO are not currently calculated, although IMO said it will develop a calculation method for CO_2 for other gases. EEXI is one of the key steps to reduce greenhouse gas emissions from the maritime sector The EEXI (Energy Efficiency Existing Ship Index) calculation aims to measure the level of energy efficiency of a ship in transporting cargo, considering the amount of carbon dioxide (CO_2) emissions produced. This process is carried out using a standard formula that has been determined by the IMO (International Maritime Organization).

F. Carbon Intensity Indicator (CII)

The CII Reference Line is a reference value set by the IMO to compare the CII achieved by a ship. These reference values are determined based on historical data that are periodically adjusted to be able to represent the expected carbon intensity values of a particular type and size of vessel. Vessels are required to achieve a CII below this reference value in compliance with regulations. This reference value is also adjusted periodically to become stricter over time. The IMO has issued guidelines for the use of operational carbon intensity indicator references through MEPC.337(76) [26]. This guideline provides guidance on the equation to determine the Reference Line CII, A CII (Carbon Intensity Indicator) is an indicator used to measure the level of pollution produced by ships by comparing the carbon emissions emitted by ships with the benefits provided through the transport of goods at sea. The CII rating system has five levels: A, B, C, D, and E, which reflect the efficiency level of the vessel. A rating indicates the best performance, while E indicates the worst performance. Ships with a D or E rating for three consecutive years are required to submit an improvement plan to achieve a better rating (minimum C).

The calculation of the CII value begins by looking for the CII reference value which can be calculated with the following formula:

$$CII_{ref} = \text{a} \times ship\ capscity^{\text{-c}} \qquad (2)$$

With,

CII ref : Reference CII,

Capacity : Ship capacity

The values of constants a and c depend on the type of ship and the capacity of the ship, and after obtaining the reference CII value, the Required CII value is also required which is calculated by the equation:

$$Required\ \text{CII} = CII_{ref} \times \frac{(100-\text{Z})}{100} \qquad (3)$$

With,

Required CII: the value of the CII needed in the coming year,

CII ref : CII reference,

Z : reduction factor in that year.

Where the value of the reduction factor increases every year. After calculating the CII req, a comparison is made with the Attained CII value to get a CII rating. The Attained CI value is generated by the equation:

$$Attained\ \text{CII} = \frac{\text{CO}^2}{Deadweight \times Distance\ travelled} \qquad (3)$$

From that equation, it is obtained that the ship's rating value is at a certain rating.

G. Green House Gas (GHG) Rating Score by Rightship

The Green House Gas (GHG) Rating Score is a rating system used to measure and assess the impact of greenhouse gas (GHG) emissions from ships. The system provides a score based on how efficient the ship is in managing fuel consumption and CO_2 emissions generated during operation. This assessment aims to encourage ships to reduce emissions and improve operational sustainability. This score is calculated by considering various factors, such as:

1) Ship design
2) Fuel Consumption
3) Ship Size

This GHG Rating Score informs ship owners, operators, and the shipping industry about how environmentally friendly a ship is and helps stakeholders to make better decisions regarding the management of their ships and their operations more sustainably. With a rating scale from A to E, where A indicates a ship with very low CO_2 emissions (very efficient) and E indicates a ship with very high emissions (less efficient).

III. RESULT AND DISCUSSION

A. Ship Data and Prognosis Data

The ship that is the object of this research is a ship with type 2000 Pax passenger with a 3 in 1 model used to transport Passengers, cargo, Vehicles, and containers, is owned and operated by PT XYZ Company, and serves domestic shipping routes. The technical data used includes the main size of the ship, tonnage, carrying capacity, type and power of the main engine, auxiliary engines, as well as information on shipping routes and fuel consumption. The data was obtained from ship technical documents, shipping databases, and official sources of ship operators. This information is then used as a basis for calculating the Carbon Intensity Indicator (CII), fuel emission factors, and analyzing the operational feasibility of the ship. Within the limitations of this study, the Ship B ship operates with an operating pattern with a route that has 1 port origin point and 5 different port destinations or commonly called liner shipping and the Ship A ship operates with an operating pattern with a route that has 7 port origin points and 7 different port destinations or commonly called liner shipping.The assessment of the Carbon Intensity Indicator (CII) value and its rating in this study is based on information related to fuel consumption and ship sailing distance on.

So that fuel consumption (BBM) can be estimated to estimate the ship's energy needs in the future period based on historical trends in fuel use. The trendline method is used to identify patterns of changes in

TABLE 2.
FUEL CONSUMPTION 2023-2025

Consumtion Fuel	Ship A	Ship B
2023	10361987	11475971
2024	10594230	11120588
2025	11382579	11586050

fuel consumption over time, so that it can be the basis for predicting CO_2 emissions, Carbon Intensity Indicator (CII) values, and future operational feasibility of ships. The following is a graph of the fuel consumption results for the Ship A and Ship B.

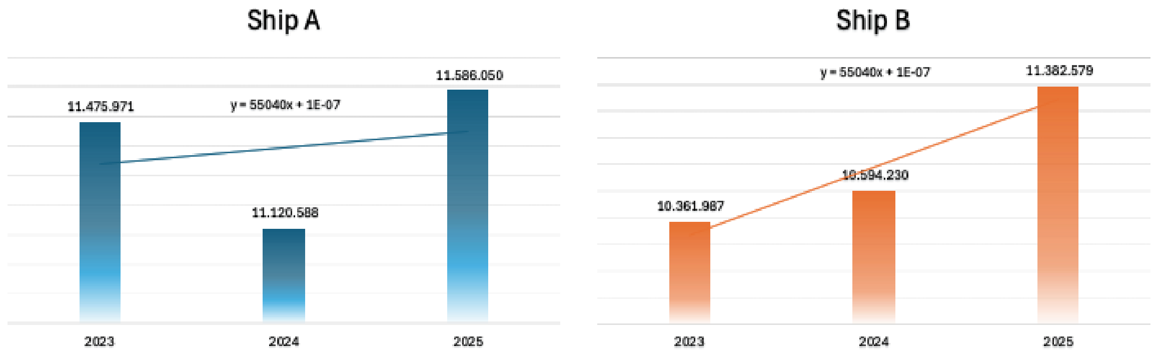


Fig 1. Data Fuel 2023-2025

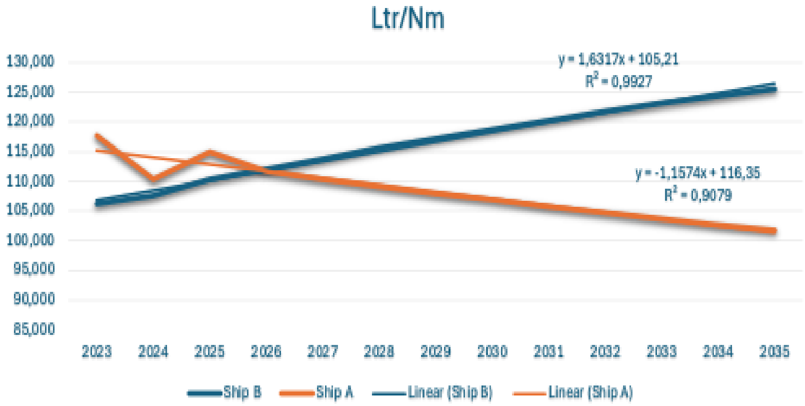
The analysis of fuel consumption trends was carried out using the linear trendline method, so that for Ship A the trendline equation was obtained $y = 55040x + 1E - 07$ and for Ship B $y = 510296x + 1E + 07$ Based on the trendline equation obtained, a fuel consumption prognosis for the next few years is calculated by entering the x value according to the projected period, so that the prognosis of fuel use for the two ships is obtained as in Table 3. Ship fuel consumption measurement is not only carried out in total usage units per year or per voyage but also expressed in operational efficiency indicators in the form of fuel consumption per unit mileage, namely liters per nautical mile (ltr/nm). The ltr/nm value represents the amount of fuel needed by a ship to travel every nautical mile and is one of the important parameters in assessing the energy performance and operational efficiency of the ship. The smaller the ltr/nm value, the more efficient the fuel use will be at the same mileage.

TABLE 1.
SHIP DATA

SHIP INFORMATION	DATA	
Ship Name	Ship A	Ship B
Year of manufacture	Kapal Penumpang	Kapal Penumpang
Spec of dimension (m)	130,00 x 23,40 x 5,89	130,00 x 23,40 x 5,90
Gt	14581	14581
Dwt	3200	3200
Load factor (assum)	1	1
Year of manufacture	1993	1991
Main Engine	MAK 6 M 601 C, 2X8500 HP	MAK 6 MU 601 C, 2X8500 HP
Fuel Type	HSD/SOLAR/B40	HSD/SOLAR/B40
Average fuel consumption liters/year	11165539	10670395
Operating routes	Rute A: Tg. Priok - Surabaya - Makassar - Bau-Bau - Sorong - Manokwari - Biak - Jayapura - Biak - Manokwari - Sorong - Bau-Bau - Makassar - Surabaya - Tg. Priok ; Rute B: Tg. Priok - Surabaya - Makassar - Bau-Bau - Sorong - Manokwari - Sorong - Bau-Bau - Makassar - Surabaya - Tg. Priok	Tg. Priok - Surabaya - Makassar - Bau-Bau - Ambon - Sorong - Serui - Jayapura - Serui - Sorong - Ambon - Bau-Bau - Makassar - Surabaya - Tg. Priok
Average nautical miles traveled annually nm	100049	97986
Engine rotation at service speed RPM	428	372
The power produced (kW/HP)	6400 kW / 428	6400 kW / 428
[illegible]	[illegible]	[illegible]

Year	Ship A	Ship B
2023	11475971	10361987
2024	11120588	10594230
2025	11586050	11382579
2026	11504282	11800191
2027	11559321	12310487
2028	11614361	12820783
2029	11669400	13331079
2030	11724440	13841375
2031	11779479	14351671
2032	11834519	14861967
2033	11889558	15372263
2034	11944598	15882559
2035	11999637	16392855

Fig 1. Prognosis Data liter per Navigable Mile



The ltr/nm indicator is calculated by dividing the total fuel consumption in liters per voyage by the total mileage traveled in nautical miles on the same voyage. Thus, the value describes the direct relationship between the energy consumption load and the actual operating distance of the vessel. , monitoring fuel consumption in LTR/NM units is one of the important considerations in operational decision-making and sustainable fleet management strategy planning.

B. Calculation of Ship CII

1) CII Reference Calculation

With a constanta a for passanger ship is 930 and c is 0.383 so,the CII Reference:

$$CII_{ref} = 930 \times 14581^{-0.383}$$

$$CII_{ref} = 23{,}645$$

1) Required CII Calculation

. This value is obtained from the results of the CII Reference correction with an annual reduction factor according to the provisions of the current year.

$$Required\ \mathrm{CII} = CII_{ref} \times \frac{(100 - \mathrm{Z})}{100}$$

$$Required\ \mathrm{CII} = 23{,}645 \times \frac{(100 - 9)}{100}$$

$$Required\ \mathrm{CII} = 21{,}52$$

2) Attained CII Calculation

The calculation of Attained CII in this section is based on data on fuel consumption and ship sailing distance during the observation period. This value indicates the actual emission intensity of the ship based on its actual operations over a year.

$$Attained\ \mathrm{CII} = \frac{\mathrm{CO}^2}{Deadweight \times Distance\ travelled}$$

$$Attained\ \mathrm{CII} = 23{,}40$$

$$CII_{ref} = \mathrm{a} \times ship\ capscity^{-c}$$

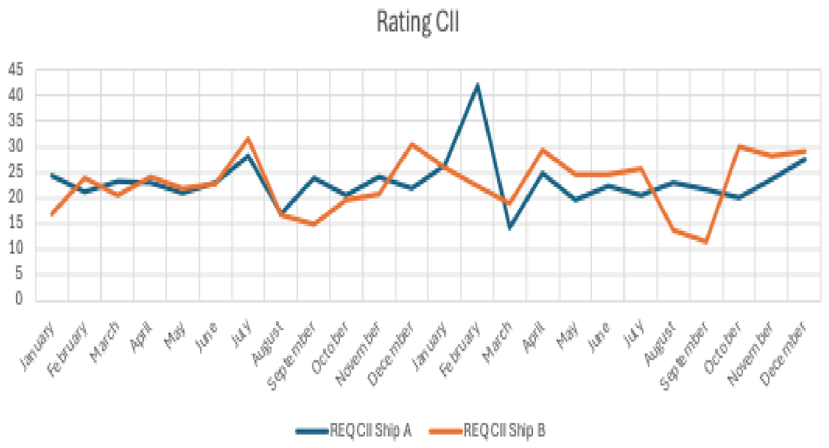


Fig 2. Rating CII 2024-2025

3) Attained Value CII Passenger Ship

The calculation of the Attained Carbon Intensity Indicator (CII) is showed in Table 4 value was carried out for Ship B and Ship A ships based on data on fuel consumption, annual CO_2 emissions, ship capacity, and operational mileage. The Attained CII value represents the actual emission intensity of the ship and is the basis for determining the CII rating in accordance with the provisions of the International Maritime Organization.

4) Monthly Attained Value of Passenger Ship CII

The results of the monthly CII analysis are used to support the evaluation of the effectiveness of technical

TABLE 4.
ATTAINED CII AND RATING CII PASSANGER SHIP

Year	Attained CII		Rating CII	
	Ship A	Ship B	Ship A	Ship B
2023	23,4	21,58	D	C
2024	22,68	22,06	D	C
2025	22,77	22,22	D	C
2026	23,46	24,57	D	D
2027	23,57	25,63	D	E
2028	23,69	26,7	D	E
2029	23,8	27,76	E	E
2030	23,91	28,82	E	E
2031	24,02	29,88	E	E
2032	24,13	30,95	E	E
2033	21,58	32,01	E	E
2034	22,06	33,07	E	E
2035	22,22	34,13	E	E

actions taken during docking as well as as as a basis for assessing their contribution to the improvement of annual CII performance and the sustainability of ship operations. As shown is Figure 2. The results of the calculation of the monthly CII value showed that after the implementation of docking activities, there was a decrease in the CII value by 15% compared to the period before docking. This decrease indicates a significant increase in the ship's carbon efficiency, which is mainly influenced by improvements in hull condition, propulsion system, and engine performance optimization. The results confirm that docking activities make a real contribution to improving CII's performance and supporting the achievement of overall ship carbon efficiency.

C. Economic Analysis

The following table presents a comparison of the financial performance of Ship B and Ship A which includes the components of revenue and shipping expenses. This data is used to analyze the operational cost structure, revenue dynamics, and their implications for operational efficiency and sustainability of passenger fleet management.

TABLE 5.
REVENUE COSTS AND EXPENSES

Cost of Revenue	Ship A			Ship B		
Total shipping revenue	216450	244230	254030	247007	253372	290405
Total shipping revenue (non pso)	98298	112395	124836	123347	124088	104658
Fuel load	76344	78376	80113	88125	81069	86703
Vessel maintenance load	25476	49502	43698	19125	37280	65178
Fixed load amount	76356	94690	94874	66503	77216	112385
Total shipping load	181484	204707	211435	189079	195830	231989

Based on a comparison of the financial performance of Ship B and Ship A, the shipping revenues of the two ships have increased, both in total and non-PSO, although with different characteristics. Ship B showed consistent non-PSO revenue growth, while Ship A experienced a decline in non-PSO revenue in the final period, indicating an increasing reliance on PSO revenue. In terms of load, fuel load and ship maintenance are the dominant components on both ships and show an increasing trend, especially on Ship A which experienced a significant spike in maintenance costs. The increase in the number of fixed loads and total shipping loads on both ships reflects increasing operational cost pressures. If PSO revenue is not taken into account, then the non-PSO shipping revenue on both ships is not able to cover the total operational load, so the ship's operations have the potential to suffer losses. Overall, these conditions suggest that despite increased revenues, a relatively faster increase in load has the potential to depress operational efficiency and sustainability performance of ships, necessitating cost control and sustainable energy efficiency improvements.

TABLE 6.
ANALYSIS OF SHIP A ELIGIBILITY RESULTS

Detail	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Ship Old	34	35	36	37	38	39	40	41	42	43	44	45	46
Attained CII	20,06	22,06	22,22	22,85	23,22	23,58	23,91	24,23	24,54	24,83	25,11	25,37	25,63
Rating CII	B	C	C	D	D	D	E	E	E	E	E	E	E
Ltr/Nm	106,159	107,517	110,299	111,989	113,814	115,546	117,194	118,762	120,257	121,684	123,047	124,35	125,597
Shipping Revenue	216450	244230	234030	249150	257941	266731	275521	284311	293101	301891	310681	319471	328261
Shipping Revenue (Non PSO)	98298	112395	104836	111715	114984	118253	121522	124792	128061	131330	134599	137868	141138
Shipping Load	181484	204707	211435	229161	244137	259113	274089	289065	304041	319017	333993	348969	363945
L/R Gross Shipping	34966	39523	22595	19989	13804	7618	1432	-4754	-10940	-17126	-23312	-29498	-35684
L/R Gross Shipping (Non-Sub)	-83186	-92313	-106599	-117446	-129153	-140860	-152567	-164273	-175980	-187687	-199394	-211101	-222807

D. Analysis of Eligibility Results

The Feasibility Decision Analysis was conducted to assess the operational and financial performance of Ship B and Ship A throughout the 2023–2035 period. This study includes several main indicators, namely the age of the ship, the Attained CII value, CII rating, fuel consumption per nautical mile (ltr/nm), shipping revenue, shipping load, and gross profit/loss both subsidized and unsubsidized (non-PSO). Through this scenario analysis, an overview of the development of energy efficiency and ship's financial performance in the projection period can be obtained, as well as providing a basis for consideration in the formulation of operational strategies, fleet management, and managerial decision-making in the future.The results of the Ship A as shown in Table 6 scenario analysis show that in the 2023-2035 projection period, there will be an increase in the life of the ship which has an impact on decreasing operational efficiency. The Attained CII value tends to increase from year to year, followed by an increase in fuel consumption per nautical mile (ltr/nm). This condition indicates that emissions per unit mileage are increasing, so that the ship's environmental performance is decreasing. This is in line with the change in CII's rating which moved from categories B and C at the beginning of the period to category D, until finally entering category E.From a financial point of view, shipping revenues still show positive value, but the increasing pressure of operating expenses caused gross profit/loss to gradually decrease.

In the non-subsidized (non-PSO) segment, performance even showed consistently negative results. Based on this projection, Ship B will receive a CII E rating for the second time in 2031. With these conditions, strategic decision-making is needed in the form of scrapping or repowering, so that ships continue to comply with CII regulations, improve energy efficiency, and maintain the sustainability of the company's operations.The projection results for Ship A show the dynamics of CII's performance that are different from Ship B. Ship A's Attained CII value tends to improve in the first few years of the projection, but as the ship ages and the fuel consumption value per nautical mile increases, the energy efficiency trend begins to decline. The ship's CII rating fluctuates in categories C and D, and in the following period enters category E. Ship A again obtained a category E CII rating for the second time in 2033, which shows that the ship is repeatedly at the level of carbon emission inefficiency.The acquisition of an E rating twice in a row has operational, financial, and compliance with international regulations. Operationally, the E rating is an indicator that the ship has experienced a significant degradation of technical performance so that fuel consumption becomes inefficient.

Financially, this has a direct impact on the increased burden of fuel costs which is the largest component of the shipping cost structure, which is reflected in decreased profitability especially when subsidies are not considered. From a regulatory aspect, ships with repeated E ratings need to undergo corrective actions in accordance with IMO regulations, including the preparation of a Corrective Action Plan (CAP).Taking into account the age of the ship that has passed 40 years, the trend of increasing energy consumption per nautical mile (ltr/nm), the decrease in profitability in the non-subsidized scenario, and the acquisition of a CII E rating for the second time in 2033, Ship A has also entered a critical phase for strategic decision-making. Alternative decisions that can be considered are scrapping if the ship is considered technically and economically unfeasible, or repowering and retrofitting energy efficiency technology if the ship is still structurally and marketably feasible. This decision is very relevant in the framework of the maritime sector's energy transition, reducing national GHG emissions, and adjusting to the demands of the shipping industry which is increasingly oriented towards sustainability.

E. *Repowering Scenario*

The repowering scenario was prepared as an alternative strategy to improve energy performance and comply with CII regulations on passenger ships which shows a downward trend in operational efficiency. Repowering in this context is defined as the activity of replacing the main engine and/or propulsion system as well as improving energy efficiency supporting technologies, with the aim of reducing fuel consumption and greenhouse gas emissions. This scenario applies to vessels that have repeatedly entered the CII rating downgrading limit to category D or E, so structural improvement measures are required to maintain operational feasibility and compliance with IMO.

TABLE 7.
SCENARIO ANALYSIS BEFORE AND AFTER REPOWERING

	Ship A	Ship B
Year	2033	2031
VOY	21	20
BBM	11889558	14351671
Distance	114691	119342
Distance/voyage	5461	5967
Time/voyage	358	388
After Repowering	303	298
kg/h	1315	1540
BBM After Repowering	6970143	7535126

In this sub-chapter, the projected impact of repowering on the Attained CII value, fuel consumption per nautical mile, and its implications on the ship's financial performance is presented. The calculation is carried out assuming an increase in engine efficiency and a decrease in fuel consumption after repowering. The following table presents the results of a comparison of the ship's performance before and after repowering in the projection period.Based on the results of the calculations in the repowering scenario table, the implementation of repowering provides a very significant and comprehensive performance improvement in the energy performance of both ships. The Attained CII value has decreased significantly compared to pre-repowering conditions, indicating a reduction in carbon emission intensity per unit payload and mileage. This improvement in energy performance is directly reflected in the change in CII rating, where after repowering, Ship B and Ship A both achieved a CII rating of category A.

TABLE 7.
SCENARIO ANALYSIS BEFORE AND AFTER REPOWERING

CII (GT)	Units	Ship A	Ship B
Required CII	gCO2/ton-mile	21,52	21,52
Attained CII	gCO2/ton-mile	14,52	16,68
Rating %	%	0,68	0,78
Rating (A-E)	Rating (A–E)	A	A
EEOI (GT)	gCO2/ton-mile	14,52	16,68
Annual CO2 Emissions	ton/year	21562	22707
Annual NOx Emissions	ton/year	135	135
Annual SOx Emissions	ton/year	91	91
Annual PM Emissions	ton/year	8	8

Before repowering, both ships had the potential to be in category D or even E due to the tendency to increase the value of CII over time. However, after the repowering was carried out, the data in the table showed a shift in the rating towards the best category, indicating a high level of emission efficiency and full compliance with CII regulations. With the achievement of this A rating, ships not only meet the minimum regulatory limits, but also have a wider tolerance for potential future performance declines due to ship aging, operating patterns, and route dynamics. This condition provides an opportunity for companies to optimize their operating schedules, route arrangements, and commercial strategies without high compliance pressure. In addition, the A rating also improves the company's competitiveness and environmental image, as ships are categorized as having excellent emissions performance. Thus, the results of the table analysis confirm that repowering not only lowers the value of CII and fuel consumption, but also significantly improves operational sustainability, extends economic life, reduces the risk of scrapping, and strengthens the fulfillment of the shipping sector's decarbonization targets.

IV. CONCLUSION

Based on the results of calculation analysis and algorithm testing, it can be concluded that Ship B and Ship A have currently exceeded the economic life of use, where Ship B is 34 years old and Ship A is 33 years old. Projections using the trendline regression method show that under conditions without subsidies, losses occur from the beginning of the period and continue to increase every year. Meanwhile, in the subsidy scenario, the gross profit/loss of shipping for Ship B has shifted from positive conditions at the beginning of the period to negative starting in 2028, while Ship A is still in a positive condition throughout the projection period.In terms of the environment, the average percentage increase in the value of the Carbon Intensity Indicator (CII) shows an increasing trend, which is 0.56% for Ship B and 2.09% for Ship A. Correspondingly, the CII ratings of both ships also show a tendency to deteriorate over time.

For Ship B, the CII rating changed from B in 2023 to C and D in the following period, until it reached an E rating in 2029–2035, so operational decision-making is needed in 2031. As for Ship A, the CII rating changed from D in 2023 to C in 2024, then returned to D in the following period, and reached an E rating in 2031–2035, so operational decision-making was needed in 2033.Based on the fuel consumption scenario in the repowering action, the increase in ship operation efficiency was seen significantly in both research objects. At Ship B, annual fuel consumption decreased from 11,889,558 liters to 6,970,143 liters, or a reduction of 4,919,415 liters, which is equivalent to a saving of around 41.4% from initial consumption. At Ship A, annual fuel consumption decreased from 14,351,671 liters to 7,535,126 liters, or decreased by 6,816,545 liters, which is equivalent to a saving of around 47.5%. The results of the analysis also showed that the post-repowering CII rating increased to an A rating in Ship B and Ship A.

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