Journal of
Marine Science and Engineering

MDPI

Article

Proposals on Effective Implementation of the Carbon Intensity Indication of Ships

Mingyu Kim, Jung-Yoon Lee, Samel An and Dae-Jung Hwang *

Korea Maritime Cooperation Center, 492 Hannuri-daero, Sejong-si 30103, Republic of Korea; mingyu.kim@imkmc.or.kr (M.K.); jylee@imkmc.or.kr (J.-Y.L.); samela@imkmc.or.kr (S.A.)
* Correspondence: hdaejung@imkmc.or.kr

Abstract: The Carbon Intensity Indicator (CII) regulation is a short-term measure of IMO for reducing GHG emissions from ships. In addition, the 2023 IMO GHG Strategy describes that the CII regulation is anticipated to create a potential synergy effect with other measures. Accordingly, the CII regulation, which took effect in 2023, is forecast to increasingly impact international shipping and the commercial vessel market. However, efforts to improve energy efficiency and implement slow steaming for ships are insufficient to meet the CII regulation that is increasingly stringent over time. Therefore, there is a growing need for fundamental improvements in future response strategies. In this study, major causes of low CII ratings for ships were investigated from a recent consulting project that was conducted to support shipping companies in satisfying the regulation from operational and technical perspectives. Lastly, proposals to implement the CII regulation effectively and to reduce GHG emissions from ships fundamentally were made, taking into account the major causes derived from the consulting.

Keywords: Carbon Intensity Indicator (CII); Greenhouse Gas (GHG); IMO GHG Strategy; IMO Data Collection System (DCS); international shipping

Citation: Kim, M.; Lee, J.-Y.; An, S.; Hwang, D.-J. Proposals on Effective Implementation of the Carbon Intensity Indication of Ships. *J. Mar. Sci. Eng.* **2024**, *12*, 1906. https://doi.org/10.3390/jmse12111906

Academic Editor: Tie Li

Received: 9 September 2024
Revised: 16 October 2024
Accepted: 22 October 2024
Published: 24 October 2024

1. Introduction

Due to the adoption of the Protocol amending Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) and Conference Resolution 8 to address CO_2 emissions from ships in 1997, it was determined that IMO should investigate Greenhouse Gas (GHG) emissions from ships and develop viable strategies to reduce their emissions [1]. In 2000, IMO published the first report focusing on the identification of GHG reduction measures and their potential, which paved the way for a roadmap for the development and implementation of future IMO GHG reduction strategies [2].

At the IMO Assembly held in 2003, Resolution A.963(23) was adopted, whilst the Marine Environment Protection Committee (MEPC) was instructed to identify and develop mechanisms necessary to limit or reduce GHG emissions from international shipping [3]. Subsequently, IMO adopted amendments to MARPOL Annex VI, which added a new Chapter 4 to the Annex to make the Energy Efficiency Design Index (EEDI) mandatory in 2011 [4].

In 2016, MEPC 70 adopted the *Road map for developing a comprehensive IMO strategy on reduction of GHG emissions from ships*. Following the Road map, the Inter-Sessional Working Group on GHG (ISWH-GHG) was established to initiate discussions on developing the IMO GHG strategy, and at MEPC 72 in 2018, the *Initial IMO Strategy on reduction of GHG emissions from ships* (the Initial IMO GHG Strategy) was adopted [5].

The Road map and Initial IMO GHG Strategy explicitly elucidate the key date for the adoption of a Revised IMO GHG Strategy: Spring 2023 (MEPC 80). Thus, MEPC 77, held in 2021, initiated the revision of the Initial IMO GHG Strategy with the aim of its adoption by MEPC 80. Throughout ISWG-GHG 15 and MEPC 80, several informal meetings were convened to narrow the gaps in each Member State's positions. Following extensive discussions, the *2023 IMO Strategy for the Reduction of GHG from Ships* (the 2023 IMO GHG Strategy) was finally adopted [6]. Compared to the Initial IMO GHG Strategy, the level of ambition has significantly increased, demonstrating a strong intention to decarbonise international shipping. In particular, energy, fuel, and technology goals for zero or near-zero GHG emissions by 2030 were introduced as new targets. Total GHG emissions checkpoints for 2030 and 2040 were added as an indicator for achieving the IMO 2050 target. The IMO's goal setting for 2030, which is about six years away, will impose a lot of technical, economic, and political burden despite the decarbonization technology of international shipping, which has grown to a significant level in a short period.

In 2022, the IMO adopted Resolution MEPC.346(78), establishing guidelines for the Ship Energy Efficiency Management Plan (SEEMP) to standardise energy efficiency management on board. SEEMP incorporates strategic measures aimed at optimising fuel consumption and GHG emissions [7]. Additionally, Resolution MEPC.364(79) provides methodologies for calculating EEDI for new ships, quantifying fuel efficiency as a compliance benchmark. These guidelines support efficient fuel use and adherence to environmental regulations in new vessel design, aligning with broader GHG reduction goals of IMO in maritime operations [8].

As a short-term measure to achieve the IMO target, MEPC 76 adopted amendments to MARPOL Annex VI concerning the carbon intensity of ships in operation as Resolution MEPC.328(76) in 2021 to implement the Carbon Intensity Indicator (CII) regulation [9]. MEPC 78 adopted technical guidance to facilitate its implementation, including methodologies for calculating CII ratings, ship-specific criteria, and correction factors. Finally, MEPC 80 established a plan to complete the review by 1 January 2026 by recalling regulation 28.11 of the amendments to MARPOL Annex VI [9].

The first official CII ratings are expected to be assigned in the first half of 2024, based on operational data from 2023. Even though the first CII ratings have not yet been officially assigned, the CII rating of ships, which can be calculated from previously submitted IMO Data Collection System (DCS) information, has already begun to impact the liquidity of vessels in the sale and purchase market. VesselsValue, a UK-based ship valuation service, analysed that the CII ratings could be perceived as an indicator of energy efficiency and competitiveness in the ship trading market, which affects trading liquidity, with different CII ratings showing distinct trading tendencies. Numerical evidence suggests that these tendencies are particularly shown in bulk carriers and tankers [10]. In this respect, the CII regulation is not only an IMO environmental regulation aimed at promoting GHG reduction and energy efficiency but also has a ripple effect on the entire international shipping market and serves as a sensitive issue for shipowners.

Regarding recent studies on the implementation of the CII regulation, [11] proposed that more elaborate models combined with real data be developed to achieve the utmost carbon emissions reduction from ships. [12] suggested that the actual cargo volume carried instead of the ship's Deadweight Tonnage (DWT) for CII calculations be used to improve the accuracy in estimating the energy efficiency of international shipping. For the reduction of the CII, [13] found that, from their analysis of 1-year routes of ships, Just-In-Time (JIT) arrival and close cooperation between shipowners and charterers are very important to improve the CII rating.

In addition, modifications in the CII formula and a new technique for the calculation of the average CII, together with a mechanism of voyage-based data collection and verification, were proposed by [14]. Regarding fishing vessels, the energy efficiency indices of eight large purse seine fishing vessels were analysed comprehensively to promote decarbonisation further in the maritime sector [15].

The CII regulation is affected by operational factors, which makes it relatively challenging for small- and medium-sized shipping companies to implement it compared to large shipping companies. Considering this situation, the government of the Republic of Korea commenced the 'CII rating improvement consulting project' to support the effective implementation of the CII regulation, especially for small- and medium-sized shipping companies in the Republic of Korea.

The major factors affecting the CII regulation and recommendations for its improvement, derived from this study, were concisely organised in a document for relevant IMO agenda and formally proposed to MEPC 80.

2. Background of the Study

2.1. Carbon Intensity Indicator (CII)

Under Regulation 28 of MARPOL Annex VI, the CII regulation came into force in 2023 as a short-term GHG reduction measure and imposes a carbon intensity rating on international navigation vessels of 5000 gross tonnage (GT) and above. The required CII for each ship is determined by multiplying the CII reference value by the reduction rate. The CII reference value is derived from a regression analysis of the carbon intensity of ships built during the period 1999–2009 and varies by size.

$$CII_{ref} = aCapacity^{-c} \quad (1)$$

where CII_{ref} is the reference value of the year 2019, Capacity is GT or DWT as indicated in the Res.MEPC.353(78) [16], a and c are parameters estimated through median regression analysis of the individual ships collected from IMO DCS.

$$\text{Required CII} = (1 - Z/100) \times CII_{ref} \quad (2)$$

where Z is the annual reduction rate for the required CII of ship types as presented in the Res. MEPC.338(76) [17].

The CII reduction rate aligns with the 2030 targets set out in the 2023 IMO GHG Strategy. The 2030 target aims for a 30% reduction in the carbon intensity of ships compared to 2008, with reductions of 1% per year from 2020 to 2022 and 2% per year from 2023 to 2026, taking into account the carbon intensity improvements achieved by 2019. The reduction rate beyond 2026 will be assigned at a later date, as the short-term measures are planned to be reviewed by 1 January 2026 to evaluate their effectiveness (Res.MEPC.338(76)). The attained CII can be calculated by dividing the annual emissions of CO_2 by transport work performed. CII ratings from A (superior) to E (inferior) are determined around a reference value. When calculating the attained CII, correction factors and voyage adjustments may be applied as follows: sailing in ice conditions, endangerment of a ship's safe navigation, shuttle tankers or oil tankers in Ship-to-Ship voyage, refrigerated containers, etc. (Res.MEPC.355(78)) [18].

$$\text{Attained } CII_{ship} = M/W \quad (3)$$

where M is the total mass of CO_2 emissions, and W is the total transport work undertaken in a given calendar year.

In accordance with Regulation 9.12 of MARPOL Annex VI, although each ship is required to carry a certificate displaying its CII rating, there is a lack of penalties for inspecting the certificate at this stage. However, ships with low CII ratings may encounter disadvantages in the sale and purchase market due to the stigma effect. Just as the 2023 IMO GHG strategy emphasises that short-term measures should be synergised with other measures, the CII regulation, as a short-term measure, would be employed in a variety of ways.

At MEPC 82 in September 2024, the Committee reaffirmed that the CII regulation's objective is to meet the 2030 carbon intensity targets outlined in the IMO 2023 strategy. A comprehensive review plan was established, classifying 21 key challenges/gaps within the current CII framework and assigning priority stages for reviews.

2.2. IMO DCS Data

IMO DCS data are used to calculate the total distance traveled and CO_2 emissions required to fulfill the CII regulation. According to Regulation 27 of MARPOL Annex VI, ships should aggregate fuel oil consumption data at the end of each calendar year and report the data to their flag Administrations or Recognised Organizations (ROs) within three months after the end of the year. Thus, shipowners need to fully understand and closely manage their fuel usage in order to accurately calculate CII and achieve a high CII rating.

Table 1 shows the revised IMO DCS format approved at MEPC 80. The main changes are the disaggregation of fuel oil consumption and the segmentation of the previously unrecognised transport work, the application of energy efficiency technology, and the onshore power supplied.

Table 1. Major amendments to the IMO DCS format (MAROL Annex 6, Appendix IX).

	Original Format (Res.MEPC.362(79))	**Revised Format (MEPC 80/17/Add.1, Annex 9)**
Fuel oil consumption data	Fuel oil consumption, by fuel oil type and methods used	Fuel oil consumption per combustion system by fuel oil type and methods used (main engine(s), auxiliary engine(s), oil-fired boiler(s), others) Fuel oil consumption while the ship is not underway
Distance travelled	Distance travelled	Total distance travelled Laden distance travelled (on a voluntary basis)
Hours underway	Hours underway	Hours underway
Onshore power supplied	-	Total amount of onshore power supplied
Total transport work	-	Total transport work Annual sum of each voyage's transport work (distances sailed multiplied by cargo carried during a voyage)
Installation of innovative technology	-	Installation of innovative technology, if applicable (A, B-1, B-2, C-1, C-2)

The original DCS format includes annual total fuel consumption data only, whereas the revised one categorises fuel consumption in a more specific way depending on the system of ships. This represents a more practical direction in terms of fuel consumption adjustments for specific cargo operations, such as cargo heating in tankers and power consumption of refrigerated containers in container vessels, as guided by the interim guidelines on correction factors and voyage adjustments for CII calculations (Resolution MEPC. 355(78)).

Moreover, only distance traveled was required in the original DCS, but the revised one allows distance to be separately included based on the cargo load. However, this requirement is voluntary in that it pertains to the commercial operation information of shipping companies.

It is also worth noting that three new items have been added. The first is to report the amount of onshore power supplied during berthing. For reference, in terms of GHG reduction and CII rating improvement, studies have shown that the use of an Alternative Maritime Power (AMP) system, which supplies a land-based electric power source (6.6 kV/3.3 kV) to a ship anchored in the port to help reduce air pollution generated from diesel generators, improves a bulk carrier's CII index by about 7.8% [19].

The use of AMP is an effective GHG reduction measure for ships since it directly helps to reduce fuel consumption [20]. However, the implementation of AMP should consider not only the financial and equipment issues needed for its infrastructure development but also human resources for ongoing management and operation after installation, as well as support for a stable power supply. While the current use of Alternative Maritime Power (AMP) presents some challenges related to human factors and effective management strategies, the European Union's 2023 'Fuel Maritime' initiative, which mandates onshore power provision for containerships and passenger vessels at major EU ports by 2030, is expected to significantly enhance the importance of AMP in the future [21].

The second is to include the amount of transport work. The CII is drawn by CO_2 emissions per transport work, and the current calculation formula uses the cargo load capacity that can be transported rather than the actual cargo transported. At MEPC 80, there was a consensus that the CII calculation process should use actual transport work rather than transportable freight loading capacity, such as DWT, for the accuracy of the CII calculation [22].

Thirdly, a new element was added to indicate whether the ship is equipped with energy efficiency technologies. IMO DCS categorises the 'Installation of innovative technology' into five categories: A, B-1, B-2, C-1, and C-2. Category A refers to technologies that directly affect the propulsion performance of the engine, such as linear optimisation and propeller geometry improvements; Category B refers to technologies that are not directly related to engine performance but can improve efficiency when applied as additional technologies, such as hull air lubrication and wind power systems. Category C refers to waste heat recovery devices that can improve efficiency as an auxiliary device separate from the ship's propulsion engine [23].

Currently, even if a ship is equipped with a separate device to improve energy efficiency, there is no benefit for shipowners under the CII regulation. However, since the introduction of the EEDI regulation in 2013, there have been changes, such as the active adoption of energy efficiency improvement devices in new ships. Considering this, it can be believed that the addition of this element to specify whether energy efficiency improvement technologies are applied will be meaningful in terms of inducing changes, such as active investment by shipowners in the application of efficiency improvement technologies.

3. CII Consulting Project and Consulting Methods

3.1. Overview of the CII Consulting Project

The consulting project was conducted to assist small- and medium-sized shipping companies in the Republic of Korea in enhancing the efficiency of their operations with lower-rating vessels and facilitating the transition towards more environmentally friendly operations.

The subject of this project is shipping companies with a potential CII rating of D or E based on the IMO DCS data in 2022. As a consulting procedure, the ships that urgently needed actions were selected for consulting among ships of shipping companies in the order they applied. Subsequently, a consortium, which specialises in eco-friendly shipbuilding and retrofitting and makes a service contract with the Korean government, analysed ship operation data such as AIS and fuel consumption data and ship and machinery specifications. The analysis provided detailed operational and technical guidelines for the implementation of CII regulations appropriate for the targeted ships and fleets of shipping companies. Consulting was conducted for a total of 12 shipping companies of the Republic of Korea that voluntarily applied. Table 1 briefly shows the shipping companies and their respective targeted ships that are subject to the consulting project.

In the Republic of Korea, most vessels with low-rated CII operated by small- and medium-sized shipping companies are bulk carriers and tankers, while container ships generally maintain favourable CII ratings. Therefore, this study primarily focuses on mainly bulk carriers and tankers. Consulting and analysis on other ship types, including container ships and LNG carriers, are planned to be conducted in the future.

3.2. Consulting Methods

The consulting was divided into two stages: operational and technical. These were structured in a way that solutions derived from both stages were not only applied to the targeted ships for consulting but also to the entire fleet owned by the shipping companies.

3.2.1. 1st Stage of Consulting: Operational Perspective

The purpose of the first stage of consulting is to propose measures to the shipping companies that could improve the CII rating of ships from an operational perspective.

In the first stage of the consulting, various operational information, including ship speed, distance traveled, fuel consumption, draft, route, etc., were presented through the analysis of IMO DCS and AIS data and the yearly trend of the Annual Efficiency Ratio (AER), which uses DWT as the capacity in evaluating the CII, was confirmed. Using these analysis data, the effect of each operational measure was calculated. Given the ship's AER value, the CII rating that the ship would achieve if it maintained the same or similar operational conditions as the current ones was projected, reflecting the increasingly stringent regulatory guidance through 2026. In addition, the improvement of the CII rating by reducing ship speed was reviewed and presented to shipping companies. Slow-steaming is one of the most accessible options for shipping companies to reduce GHG emissions and satisfy the CII regulation without the need to consider or invest in new technology. However, indiscriminately reducing vessel speed can cause arrival time to a destination port and consequently influence the contractual agreements for the transportation of cargo.

In addition, by utilizing the data of ships disclosed in EU MRV, similar ships within a $\pm$5% error range of DWT of the target ship were analyzed and compared. Through the CII grade distribution table, an indicator was identified to determine the current position of the ship and how to determine the direction of improvement accordingly.

Figure 1 shows examples of the analysis and consulting results aforementioned.

CII rating improvements by using alternative fuels such as biofuel, LNG, and methanol were also examined, as presented in Figure 2. Biomarine fuel, currently available in some ports globally, was reviewed based on B30 biofuel due to it being the closest to commercialisation among alternative fuels. A blending rate of biofuel to improve CII rating was also presented to shipping companies. Additionally, improvement of CII rating by using other alternative fuels, including LNG, methanol, LPG, and e-fuel, were examined to meet regulatory requirements over the coming years for more information to shipping companies.

Figure 2 provides an example of a vessel from the consulting project, displaying its AER index across various fuel types. The orange and yellow dashed lines represent the 2018 and 2023 GHG reduction targets of IMO, respectively. This visualization shows the degree to which different alternative fuels meet these targets under the vessel's operating conditions, highlighting the potential impact of commercially available conventional fuels.

3.2.2. 2nd Stage of Consulting: Technical Perspective

The second stage of consulting reviewed technical elements such as equipment applied to the main and auxiliary engines of the vessels, as well as the applicable ESDs for improvement of their energy efficiency. Furthermore, the consulting examined the technical measures that can be realistically applied to the vessels with estimated investment costs and payback time for each measure. Then, the results were presented to the shipping companies, and further discussion was held on the implementation of the measures.

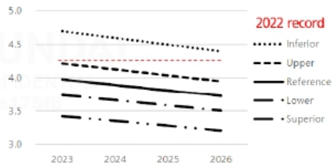
Table 2 shows the primary technical measures investigated to improve the energy efficiency of ships. In terms of managing the main engine, calculations were conducted for the operable Energy Efficiency Existing Ship Index (EEXI) and minimum propulsion horsepower with an estimation of the optimal operating point. Moreover, the results of fuel efficiency improvement, which could be achieved through the application of ESDs such as Propeller Boss Cap Fin (PBCF) and Pre-Swirl Duct (PSD) through stern modifications, were presented to shipping companies.

- General vessel information

Vessel type	Main dimension				Capacity	
	Length (O.A.)	Breadth	Depth	Draught	Deadweight	GT
Bulk carrier	229	32	20	14.5	81,399	44,102

- AER requirements

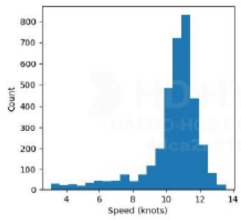
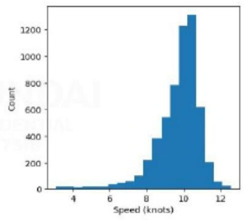
Target period	Bourdary				
	Inferior	Upper	Reference	Lower	Superior
2023	4.69	4.22	3.98	3.74	3.42
2024	4.59	4.13	3.89	3.66	3.35
2025	4.50	4.04	3.81	3.58	3.28
2026	4.40	3.95	3.73	3.50	3.20

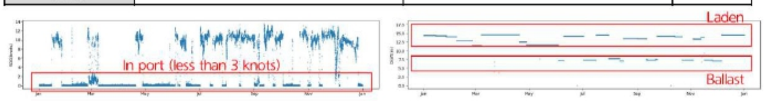


- Analysis for previous calendar year (2022)

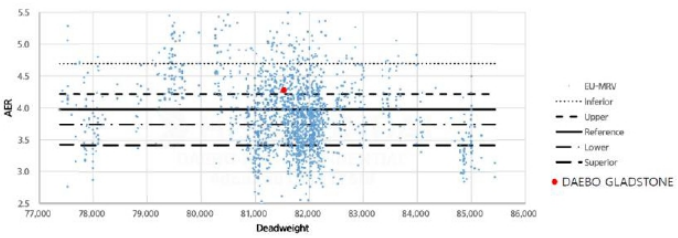
Source	Distance (NM)	LFO (MT)	MGO (MT)	CO2 (MT)	AER	Expected CII rating			
						2023	2024	2025	2026
IMO DCS	40,320	4,233	174	13,895	4.234	D	D	D	D
LFO equi.	40,320	4,413	-	13,906	4.237	D	D	D	D

- Operation characteristics (In port condition: SOG is less than 3 knots)

	Ballast	Laden	In port
Duration	65D 9H	97D 11H	202D 4H
Distance (NM)	16,720	22,909	-
Speed profile			-
Average speed (knots)	10.7	9.8	-



- Comparison with similar vessels
(Data source: EU-MRV 2018 to 2021, Bulk carrier deadweight ±5%)



Reporting Period	Expected CII rating (For 2023 requirements)					
	A	B	C	D	E	Sum
2018	300	348	543	405	256	1,852
2019	215	334	601	401	261	1,812
2020	322	378	572	319	237	1,828
2021	202	331	716	534	357	2,140
Sum	837	1,060	1,716	1,125	754	5,492
Ratio	15%	19%	31%	20%	14%	

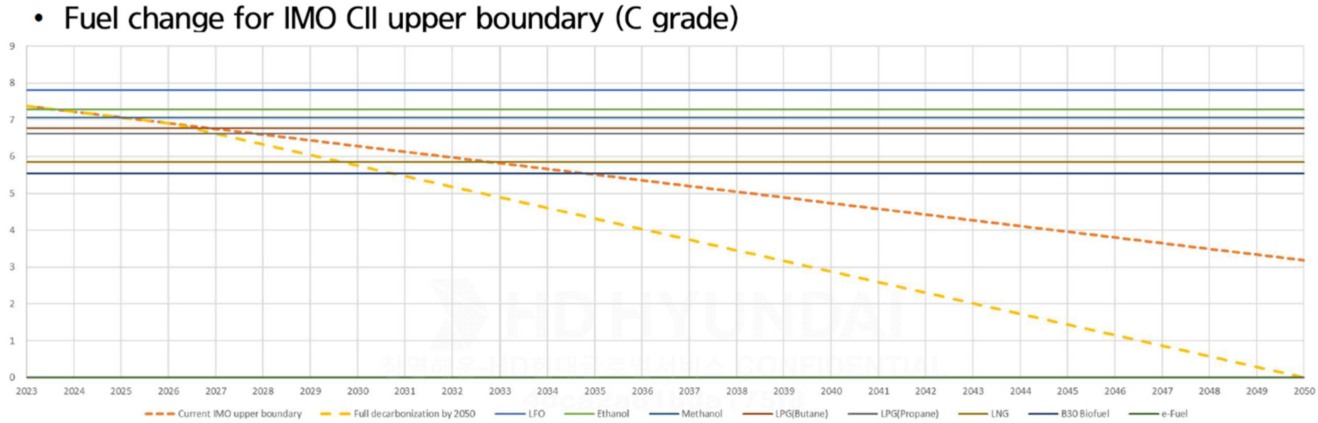
- Slow steaming approach
(speed reduction for previous calendar year)

Speed reduction (kn)	Distance (NM)	FOC (MT)	CO2 (MT)	AER	Expected CII rating			
					2023	2024	2025	2026
0.5	38,225	3,802	11,980	3.85	C	C	C	C
1	36,238	3,252	10,247	3.47	B	B	B	B
1.5	34,288	2,758	8,690	3.11	A	A	A	A

- Analysis for previous calendar year (2022)

Source	Distance (NM)	LFO (MT)	MGO (MT)	CO2 (MT)	AER	Expected CII rating			
						2023	2024	2025	2026
IMO DCS	40,320	4,233	174	13,895	4.234	D	D	D	D
LFO equi.	40,320	4,413	-	13,906	4.237	D	D	D	D

Figure 1. Examples of the analysis and results consulted for operational measures.



Fuel	Fuel characteristic				Fuel change validity		
	LCV (kJ/kg)	Cf (t-CO2/t-Fuel)	CO_2 emission compare to HFO	CO_2 emission compare to LFO	AER	Current IMO upper boundary	Full decarbonization by 2050
HFO	40,200	3.114	100.0%	101.3%	-	-	-
LFO	41,200	3.151	98.7%	100.0%	7.81	-	-
Ethanol	26,800	1.913	92.1%	93.3%	7.29	2023	2023
Methanol	19,900	1.375	89.2%	90.3%	7.05	2024	2024
LPG(Butane)	45,700	3.030	85.6%	86.7%	6.77	2026	2026
LPG(Propane)	46,300	3.000	83.6%	84.7%	6.62	2027	2026
LNG	48,000	2.750	74.0%	74.9%	5.85	2032	2029
B30 Biofuel	40,200	2.180	70.0%	70.9%	5.54	2034	2030
e-Fuel	40,200	0	0.0%	0.0%	0.00	2050	2050

Figure 2. Review of the compliance of the CII regulation with the use of alternative fuels.

Table 2. List of targeted ships for the consulting project.

No.	Shipping Company	Ship Type	DWT	Flag	Delivery Year	CII Rating
1	A	Bulker	58,655	Panama	2010	E
2	B	Bulker	42,102	Panama	2013	E
3	C	Bulker	63,203	Marshall Islands	2015	D
4	D	Bulker	43,537	Panama	2010	E
5	E	Bulker	33,144	Republic of Korea	2010	D
6	F	Tanker	12,144	Republic of Korea	2015	D
7	G	Bulker	51,265	Marshall Islands	2010	E
8	H	Tanker	11,290	Republic of Korea	2009	D
9	I	Tanker	8072	Republic of Korea	2009	D
10	J	Bulker	23,703	Republic of Korea	2010	E
11	K	Bulker	179,181	Panama	2009	D
12	L	Bulker	11,300	Republic of Korea	2006	D

The main engine modification was implemented to optimise engine load and introduce technologies such as EcoCam, EcoNozzle, and PMI VIT to achieve efficient fuel consumption, and the main engine performance of the vessel was evaluated based on these technologies. In the engine retrofit, the additional power generation effect of the waste heat recovery system was evaluated depending on whether an economiser or ORC was applied. The modification of the auxiliary engine system was considered to optimise the energy consumption of the ship system by improving the efficiency of the VFD (Variable Frequency Drive), CJC Filter, and equipment of the auxiliary engine.

Additionally, the effectiveness of PBCF and PSD was evaluated, taking into consideration the reduction in wind resistance and energy loss. Table 3 shows the primary technical measures considered to improve ship energy efficiency.

Table 3. Primary technical measures considered to improve ship energy efficiency.

Items	Main Points Reviewed and Consulted
Main Engine	- Satisfaction of EEXI requirement and minimum propulsion power based on the engine specification and load - Optimal operating point beyond the constraints of slow steaming - Confirmation of fuel efficiency for each load - Measures to improve engine and fuel efficiencies (e.g., part load optimisation of the engine)
Auxiliary Engine	- Identification and analysis of major power consumption areas of the ship based on the Electric Load Analysis (ELA) - Guidance on the parallel operation of the auxiliary engine under various conditions to determine the optimal operating point - Installation of the economiser producing additional steam through waste heat or the application of the Waste Heat Recovery System (WHRS) - Application of thermoelectric power generation and other measures to improve engine and fuel efficiencies
Hull Form and ESDs	- Commercially available ESDs (e.g., PBCF and PSD) - Applicable measures including bulbous bow optimisation, propeller re-design, and winder cover, depending on the vessel type
Digital Solution	- Management and reporting on real-time ship speed performance, weather, hull fouling, etc. - Voyage Management (e.g., weather routing, trim optimisation) - Management of daily CII ratings analysed through AER monitoring
Wind Propulsion	- Application of an onboard system that harnesses wind power for propulsion through rotor sail, particularly for tanker and bulk carriers

4. Consulting Results and Discussions

4.1. CII Rating Status of Ships Under Consulting

The left graph in Figure 3 illustrates the distribution of CII rating status and the number of ships across five major ship types owned by shipping companies in Korea, based on the IMO DCS data in 2022 through the 'Project for Implementation of Regulations to Reduce GHG Emissions from Ships' supported by the Ministry of Oceans and Fisheries, the Republic of Korea. The right graph in Figure 3 depicts the number of vessels categorised by major ship types amongst 223 CII low-rated (i.e., D and E) vessels, distinguishing the top 10 shipping companies from the others based on their operating profit in 2021.

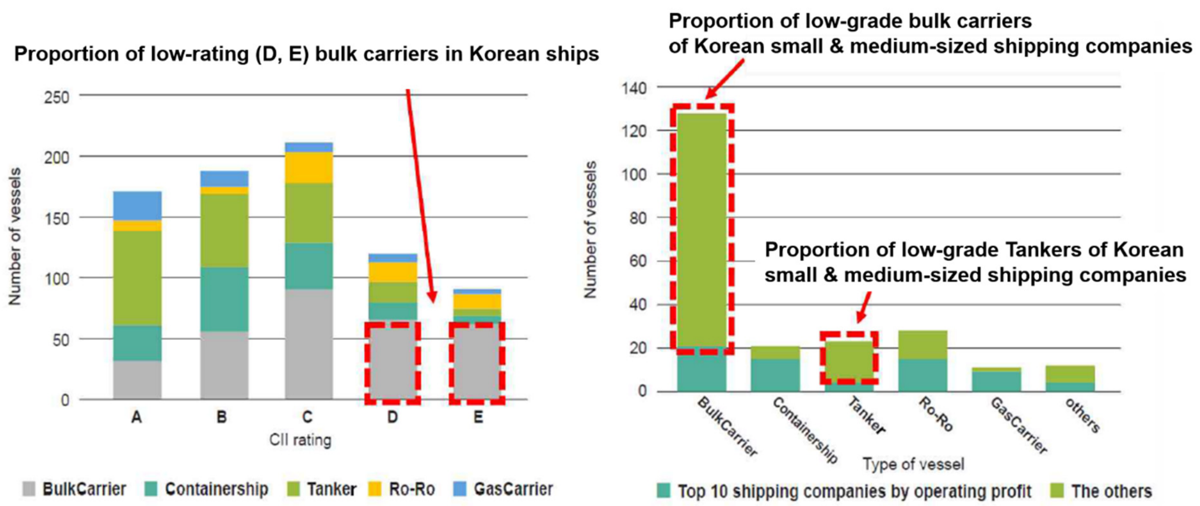


Figure 3. (**Left**) Distribution of CII rating by major ship types, (**Right**) distribution of low CII rating (D and E) by the size of shipping companies based on operating profit.

As to bulk carriers, approximately 42% fall into the CII low rating, exceeding the overall average of 26.8% across all ratings. In contrast, for container ships, the share of CII low-rated vessels is 14.3%, which is half of the overall average and one-third of the share found in bulk carriers. Tankers exhibit the lowest percentage of the CII low-rated vessels at 9.2% among all ship types.

It is worth pointing out that the CII rating process divides ships into high ratings (A and B) and low ratings (D and E) based on C as the reference value, resulting in a certain proportion of low-rated vessels. This distribution pattern resembles a normal distribution curve, which varies depending on the reduction rate and the number of ships each year. However, considering that the relatively high number of low-rated vessels is particularly shown in specific types, such as bulk carriers, it is necessary to investigate the fundamental cause from various perspectives.

The right graph in Figure 3 indicates that, for bulk carriers and tankers, the number of low-rated vessels owned by the top 10 shipping companies is notably lower compared to the others, which are assumed to be small- and medium-sized shipping companies. Ships owned by small- and medium-sized shipping companies demonstrate a relatively higher proportion of low-rating bulk carriers and tankers. It is challenging to analyse the causes of this disparity solely using IMO DCS data, which only shows distance travelled and fuel consumption, without investigating detailed factors such as the operating patterns of ships.

4.2. Major Causes of Low CII Ratings

The consulting for a total of 12 shipping companies in Korea resulted in an annual reduction of approximately 40,876 tCO_2 emissions from ships. Figure 4 shows the CII rating improvement and CO_2 reduction per year expected for each vessel for which consulting has been implemented. Based on the measures identified through the consulting, it was decided that the targeted ships could be upgraded from a D or E rating to a C rating of the CII. Operational measures, such as reducing ship speed, were adopted by most of the companies consulted, while only a few decided to invest in ESDs.

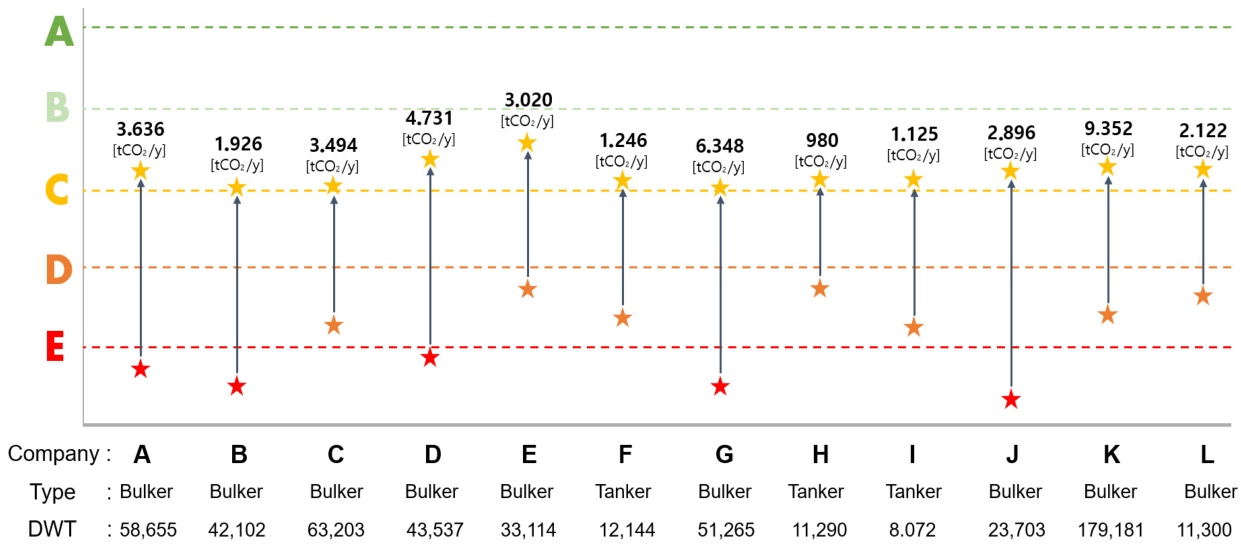


Figure 4. Improving the CII rating of each ship and reducing CO_2 emissions for consulting vessels.

During this consulting project, diverse ways to improve CII ratings were explored through providing consulting tailored to the circumstances of each shipping company. As a result, it was found that close operational monitoring and management could significantly reduce GHG emissions and improve CII ratings. It was also revealed that most shipping companies are actively considering the use of biomarine fuel.

Major causes for the low CII ratings derived from the consulting could be summarised into four elements, as outlined below.

1. Long waiting times for ships caused by port circumstances;
2. Difficulty of application of CII correction factors;
3. Deficiency of systematic policy on the CII rating management plan;
4. Lack of communication and cooperation between stakeholders.

The elements are the results of analysis only from an operational management aspect. Technical elements, including fuel transition and energy efficiency improvement by using other devices applied to engines or ships, are excluded in this study because it is generally difficult to consider them as a common element due to their variability based on the financial status of shipping companies or ship specifications.

The first element is long waiting times for ships at ports. Based on the calculation methodology of the CII ratings, prolonged waiting times in ports contribute significantly to a decrease in energy efficiency as ships sail at minimal distances and consume fuel to maintain the basic vessel systems. This element is caused by port circumstances such as congestion, port repair, etc. Issues related to arrival/departure at ports frequently arise. It is widely acknowledged that arrival/departure at port can be delayed due to various causes. The problems are that it is difficult for vessels to obtain accurate information on port circumstances in advance and to establish timely schedules to minimize the arrival/departure delays in a practical manner owing to the first-come-first-serve terminal entry practices in ports.

As a note, recognising the severity of this issue, the GEF-UNDP-IMO GloMEEP Project and members of the Global Industry Alliance to Support Low Carbon Shipping announced the issuance of the Just in Time (JIT) Arrival Guide—Barriers and Potential Solutions focusing on the reduction of waiting times of ships at ports to solve the issues [24]. However, it was confirmed that these guidelines could not be used in the industry due to external factors, such as different systems in ports and cargo owners' calls for waiting, etc. In addition, the optimisation of port calls is also included in resolution MEPC.366(79) on voluntary cooperation between ports and shipping sectors to contribute to reducing GHG emissions from ships adopted at MEPC 79 in 2022 [25].

The average number of days of navigation under 3 knots, including anchoring, drafting, and cargo operating time of the consulted ships, was 181 days in 2022 based on the AIS data of the ships. The highest number of days of navigation in these conditions was 223 days. It was confirmed that if the navigating days under 3 knots were considered port time, low CII ratings could result from using electricity for running generator engine(s) to maintain basic ship systems.

The second element is the difficulty of the application of the CII correction factors. This element was identified in the process of consulting on tankers. It was confirmed that the human elements of shipping companies that lack a close understanding and analysis of frequently revised relevant regulations are one of the causes. There are some cases where the CII correction factors can be applied to some of the targeted tanker ships. However, it is often challenging to apply due to the absence of devices, including the kWh meter counter on ships, necessary for calculating the correction factors. It was found that the implementation of the regulations related to the correction factors can be difficult because of the technical limitations of ships. This is the case where the purpose of the regulations on correction factors is not fully realised due to conditional constraints.

The third element is the deficiency of systematic policies on the CII rating management plan. Shipping companies shall report the CII rating once a year under regulation 28 of MARPOL Annex VI. In order to practically manage the CII rating and apply applicable measures to improve the ratings in advance, a system to monitor energy efficiency based on the ship's technical specifications and real-time ship operational data is required. Recently built ships tend to be installed with this system as a standard specification.

Through the consulting, it was found that many shipping companies, especially small- and medium-sized shipping companies, lack awareness of the importance of the impact of the CII regulation and effective operational management.

Lastly, the fourth element is the lack of communication and cooperation between stakeholders, especially between shipowners and charterers. The cargo contract for commercial ships can be divided into long-term and short-term charters. The shipping companies with non-liner ships with a high route variability as short-term charter transport cargoes when it is deemed beneficial at a certain time and situation of markets. "Shipping companies operating non-liner ships with high route variability engage in short-term chartering to transport cargoes when market conditions and timing are deemed favorable."

In other words, short-term chartering ships, which fundamentally need to recognise the world as a single market and secure the operating areas by themselves, respond swiftly to the changes in markets and regulations. It was also confirmed that the short-term chartering ship's stability in a cargo transportation contract tends to be relatively lower compared to the long-term chartering ships from the perspective of the CII regulation, but the short-term chartering ships can actively respond to the change of operational market environment from the view of operation efficiency through consulting with shipping companies.

On the other hand, long waiting times caused by port circumstances can be an issue for ships with long-term charter contracts under the contracts with cargo owners on cargo volume, loading and unloading, freight, rates, termination dates, and anchoring waiting conditions. Before the introduction of the CII regulation, the anchoring waiting period in the process of the navigation of long-term charter ships was not a huge deficit because cargo owners would usually pay demurrage charges to shipowners. However, as mentioned above, considering the low CII ratings caused by long waiting times at ports can affect the value of ships, long waiting times are now considered an issue shipowners should handle even if the ships are long-term chartered.

Some of the consulting ships could not avoid the long waiting times in line with the long-term charter contracts. However, if the contracts are terminated, the ships have to be put into the competition market as non-liner ships, and the ships could lose their competitiveness due to the low CII rating caused by long waiting times during previous long-term charter periods.

5. Proposals on the Effective Implementation of CII Regulations

5.1. Detailed Management of Fuel Consumption

One immediate action shipping companies could take is to closely monitor fuel consumption. The revised IMO DCS format implies the need for tighter fuel management in the future. With the introduction of alternative fuels and energy efficiency measures, precise fuel consumption management becomes even more crucial for assessing and confirming energy efficiency improvements accurately. Detailed management entails analysis of fuel consumption across wide categories, including ESDs, route-specific consumption, and cargo-related factors. Shipping companies should manage their ships comprehensively based on the analysis of their ships.

Furthermore, particularly in the case of tankers where additional fuel consumption arises from various cargo-related processes such as cargo heating, tank cleaning, and loading/unloading, it is indispensable to consider detailed fuel consumption management. Given that a mechanism of comprehensive fuel consumption management is not simply established, meticulous preparation is needed before the full-scale adoption of alternative fuels globally.

For precise measurement of fuel consumption on ships, the existing IMO CII guidelines permit the utilisation of fuel tank soundings and flow meter measurements to determine usage. Nevertheless, practical considerations may cause inaccuracies depending on the chosen method of measurement, prompting an exploration of varied and precise fuel consumption estimation methods [26]. In this regard, shipowners are urged to devise their own precise and comprehensive fuel consumption management strategies tailored to the specific characteristics of their fleet.

5.2. Active Consideration of the Use of Bio Marine Fuels

The establishment of standards for the use of biomarine fuels as interim guidelines, referencing the 'Approved Sustainability Certification Schemes' under the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) at IMO MEPC 80, stems from the fact that bio marine fuels offer the most viable immediate solution for reducing GHG emissions from ships in the short term.

Some experts highlight that considering that the production process of biofuels relies on limited resources in the long term, there may be competition in terms of supply volume with other industries. This means that biofuels might not be a long-term solution for decarbonisation strategies in the maritime sector [27]. While hydrogen and ammonia are anticipated to serve as green alternative fuels for ship propulsion in the long term, biomarine fuels could be actively conceived as a practical alternative to reduce GHG emissions from ships at present, especially for companies with CII low-rated vessels.

Biomarine fuels can be seamlessly integrated into vessels without requiring any special modifications to the traditional engine systems. Furthermore, it is expected that the distribution of biofuels to ships will become more widespread in the future, as they are relatively easy to handle at petroleum chemical terminals for storage and supply, provided appropriate temperature maintenance is ensured. However, due to their physical and chemical properties, biomarine fuels necessitate meticulous management, including temperature maintenance, unlike Heavy Fuel Oil (HFO).

5.3. Improvement of Operational Efficiency Through the Reduction of Long Waiting Times at Ports

One of the strategies to meet the CII regulation for existing vessels is to optimise operational efficiency. The key to optimisation lies in reducing the waiting times of ships at ports. Given that the denominator of the CII formula represents the distance travelled while the numerator signifies fuel consumption, consuming fuel without any distance travelled significantly contributes to lower CII ratings. Additionally, long waiting at ports poses commercial challenges. In particular, bulk carriers, which often experience extended waiting times compared to other ship types, are faced with relatively bigger economic disadvantages. Figure 5 illustrates the annual vessel berthing fees incurred during bituminous coal transportation to Korea's top five power plants. Excluding extraordinary circumstances such as the COVID-19 period, berthing fees have consistently risen. Notably, in 2022, berthing fees for Korea's top five power plants surged to about 103.9 million USD.

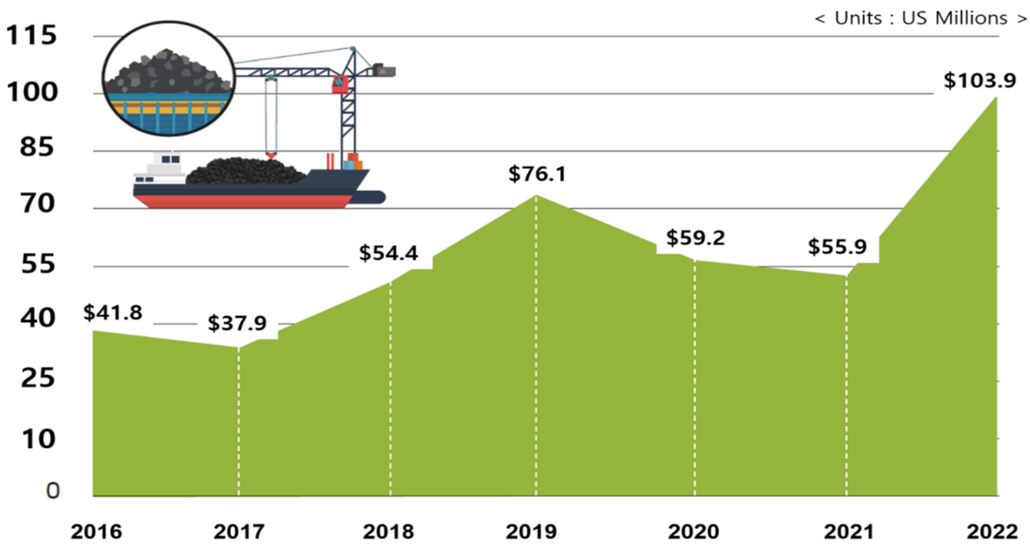


Figure 5. Trends in annual demurrage due to long-term waiting for bituminous coal transportation vessels of five major power generation companies in Korea.

While berthing fees are regarded as penalties that shipowners charge to charterers, some argue against considering them as losses. However, the absence of berthing fees could potentially allow shipowners to profit more by transporting additional cargo. Furthermore, when viewed from the perspective of both shipowners and charterers, berthing delays undoubtedly translate into economic losses.

In addition, when global environmental regulations had a minimal impact on vessel operations in the past, power plants paying berthing fees did not immediately result in losses for shipowners. However, as mentioned above, berthing delays leading to long-term anchorage now result in lower operational efficiency of vessels, reflected in lower CII ratings, ultimately impacting the value of the vessel. Considering this, it is no longer sufficient to view this solely from an economic perspective of profit and loss.

While long waiting times at ports may not directly correlate with these issues, there is a growing recognition of the need for a shift in attitudes among cargo owners towards timely vessel operations and GHG reduction for fundamental solutions. In this context, the significance of BIMCO's 'CII Operations Clause for Time Charter Parties 2022', adopted in 2022 [28], lies in imposing cooperative obligations on shipowners and charterers for CII compliance, providing grounds for measures and warnings to charterers to meet CII regulations. Similarly, the adoption of the 'CII Clause for Voyage Charter Parties 2023' in 2023 [29] enhances the shipowner's authority to adjust ship speed to reduce GHG emissions from ships.

There is a need for guidance from relevant associations and governmental bodies, based on the overarching rationale of GHG reduction and operational efficiency improvement, to rectify unjust practices in the relationship between shipping companies and cargo owners. Long waiting times at ports are thus a negative factor for shipowners' compliance with GHG reduction regulations.

One noticeable change is the shift towards responsibility shared between shipping companies and cargo owners to address GHG issues rather than placing the burden solely on shipowners. There are already various global initiatives urging cargo owners to embrace ESG management practices.

5.4. Data Sharing Between Shipping Companies and Cargo Owners for Implementing Just-in-Time (JIT) Arrival

The most straightforward and effective approach to addressing the long waiting time issue is aligning vessel arrivals with the commencement of cargo operations at ports. The approach is uncomplicated, whereas its execution may cause some complexity.

To address the issue of ships' unnecessarily long waiting times, it is crucial for ship and cargo owners to share data on cargo operations at ports. Figure 6 illustrates the collaboration between stakeholders in sharing data and the role of ports. They should collaborate to decrease congestion at ports and enhance the ship's efficient operations by ensuring punctual port arrivals. The specific cooperation involves the timely exchange of accurate data necessary for smooth operations. The data vary depending on the ship's types and terminal characteristics. It is necessary to emphasise the importance of accurate and timely data exchange, as well as a mutual willingness to exchange data.

Timely data exchange is important because data provided when vessels are already close to the port are not helpful to ensure the coordination of the on-time arrival. The establishment of a rational operation management of ships, with reduced waiting time at ports through cooperation among stakeholders, is crucial not only to reduce the GHG emissions ultimately but also to improve air quality in ports.

The reduction of GHG emissions is a global issue that requires an urgent response from shipping companies as well as cargo owners. The Zero Emission Maritime Buyers Alliance (ZEMBA), a non-profit cargo owners' group within the maritime sector, including Amazon, Patagonia, IKEA, Nike, and Philips, has announced that it is launching a request for proposals (RfP) to global shipping lines to accelerate the decarbonisation of international shipping [30]. ZEMBA is leading the way in meeting the obligations of cargo owners to reduce GHG with a tender requirement to reduce GHG emissions by at least 90% compared to fossil fuels. This is an indirect indication that cargo owners should also consider their environmental responsibilities as international companies rather than just pursuing economic benefits when entrusting their cargo to shipowners in the future in line with their ESG management.

Figure 6. Collaboration between ship and cargo owners and the role of ports to effectively implement JIT.

5.5. Management of CII Rating on a Fleet Level

While the use of biofuels, segmentation of fuel consumption, and operational optimisation are short-term measures to meet the CII regulation, management of CII rating on a fleet level is a mid- to long-term solution. Large global shipping companies with extensive fleets are already managing their CII ratings at the fleet level by employing strategies such as substituting ships expected to have lower ratings due to inefficient operations on specific routes with vessels operating on different routes.

Unlike the EEDI and EEXI regulations, the CII regulation is highly influenced by operational factors, particularly taking into account the increase in the reduction factor (Z%) for the CII. As outlined in the introduction, the CII regulation is expected to have an effect on the promotion of the scrapping of ships with low energy efficiency. Given the inherent nature of the regulation, shipping companies need to consider fleet restructuring.

In the past, 'fleet management' predominantly centred on factors such as vessel age, sale price, and business circumstances. However, with the impending enforcement of stricter economic and environmental regulations, such as carbon taxes, holistic approaches to fleet management are needed for shipping companies.

6. Conclusions

Since the adoption of the Protocol amending MARPOL Annex VI, IMO has been making efforts to reduce GHG emissions from international shipping with the identification, development, and implementation of various measures in the short and long term. It is worth noting that the 2023 IMO GHG Strategy was adopted with the target to reach net-zero GHG emissions by or around 2050, which is a significant increase compared to the Initial IMO GHG Strategy.

As one of the short-term measures, IMO adopted amendments to MARPOL Annex VI with the requirements to demonstrate operational carbon intensity reduction through CII in 2021. It is perceived that the CII rating has already begun to impact the liquidity of vessels in the market, even though the official CII ratings are expected to be assigned in the first half of 2024.

Recognising the difficulty small- and medium-sized shipping companies face in implementing the CII regulation, the Republic of Korea commenced a consulting project to support them in their implementation of the regulation. The consulting was conducted for a total of 12 shipping companies in Korea, with ships expecting a low CII rating (D and E) based on the IMO DCS data in 2022. The consulting was divided into two stages: operational and technical.

In this study, consulting methods were presented in detail from both an operational and technical perspective. In the first stage of consulting, operational characteristics for the ships and improvement of the CII rating by reducing ship speed and using alternative fuels were examined. In the second stage of consulting, technical measures such as equipment for main and auxiliary engines and ESDs were reviewed for the ships, along with investment costs and payback time for each measure.

Secondly, the CII rating status for ships owned by shipping companies in Korea was analysed. It was confirmed that the relatively high number of low-rated vessels is particularly shown for bulk carriers, and ships owned by small- and medium-sized shipping companies demonstrate the relatively high proportion of low-rated bulk carriers and tankers.

Through the consulting, the average annual CO_2 reduction per vessel was approximately 3406 tCO_2/y. When analyzed on a DWT basis, bulk carriers achieved an average reduction of about 74.16 tCO_2 per 1000 DWT, while tankers demonstrated a higher reduction rate of about 106.15 tCO_2 per 1000 DWT, indicating that CO_2 reduction potential for tankers is higher than that for bulk carriers. This disparity is likely to come from CII adjustments for tankers in the current G5 guidelines. During the consulting process, strategic recommendations were provided to take full advantage of these adjustment factors. This approach aligns with the structural considerations within the G5 guidelines that account for operational characteristics and emission reduction demands specific to tankers, thereby enhancing their reduction potential.

Thirdly, major causes of low CII ratings were derived from the consulting as follows: long waiting times for ships at ports, the difficulty of the application of the CII correction factors, the deficiency of systematic policies on the CII rating management plan, and the lack of communication and cooperation between stakeholders.

Lastly, proposals for the effective implementation of the CII regulation were made, taking into account the major causes of low CII ratings. It is believed that detailed management of fuel consumption, consideration of the use of biofuels, reduction of long waiting times at ports, data sharing between stakeholders for JIT arrivals, and management of CII rating on a fleet level are crucial for the effective implementation of the regulation and fundamental reduction of GHG emissions from ships.

The impact of the CII regulation on reducing carbon intensity in ship operations has grown significantly. It has evolved from a dimension where simply improving ship energy efficiency by shipowners could address regulations such as the EEDI and EEXI regulations to a multifaceted matter requiring collaboration among various stakeholders. Therefore, all stakeholders, including ship owners, charterers, cargo owners, and port authorities, should collaborate not only to implement the CII regulation but also to promote their ESG management.

To address complex CII and GHG regulations, it is crucial for government and public institutions to lead in creating neutral communication platforms among stakeholders. Effective collaboration in a competitive market environment requires structured support, especially during this decarbonisation transition.

Future research will explore strategies to support the practical revision of CII regulations and assess the sustainability and economic feasibility of alternative fuels, considering environmental and economic factors. Additionally, the research will analyze the broader economic impacts of CII regulations, particularly focusing on small- and medium-sized shipping companies.

Author Contributions: M.K.: overall structure, conceptualisation, Section 3 and Conclusions; J.-Y.L.: review and Sections 1 and 2; S.A.: review and Sections 2 and 3; D.-J.H.: conceptualisation, and Sections 3–5. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by Korea Institute of Marine Science & Technology Promotion (KIMST) funded by the Ministry of Oceans and Fisheries, Korea (RS-2022-KS221683).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IMO. Conference Resolution 8: CO_2 Emissions from Ships, 1997. Available online: https://wwwcdn.imo.org/localresources/en/MediaCentre/PressBriefings/Documents/MP%20CONF.3%2035%20Resolution%208%201997%20CO2.pdf (accessed on 5 September 2024).
2. IMO. Study of Greenhouse Gas Emissions from Ships, 2000. Available online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/First%20IMO%20GHG%20study.pdf (accessed on 5 September 2024).
3. IMO. *IMO Policies and Practices Related to the Reduction of Greenhouse Gas Emission from Ships (Resolution A.963(23))*; International Maritime Organization: London, UK, 2003.
4. IMO. *Report of the Marine Environment Protection Committee on Its Sixty-Second Session (MEPC 62/24)*; International Maritime Organization: London, UK, 2011.
5. IMO. *Initial IMO Strategy on Reduction of GHG Emissions from Ships (Resolution MEPC.304(72))*; International Maritime Organization: London, UK, 2018.
6. IMO. *Draft Report of the Marine Environment Protection Committee on Its Eightieth Session (MEPC 80/17)*; International Maritime Organization: London, UK, 2023.
7. IMO. *Guidelines for the Development of a Ship Energy Efficiency Management Plan (Resolution MEPC.346(78))*; International Maritime Organization: London, UK, 2022.
8. IMO. *Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships (Resolution MEPC.364(79))*; International Maritime Organization: London, UK, 2022.
9. IMO. *Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships, 1973, as Modified by the Protocol of 1978 Relating Thereto (Resolution MEPC.328(76))*; International Maritime Organization: London, UK, 2021.
10. Rowse, S. VesselsValue: CII Already Impacting Sale and Purchase, 2023. Available online: https://www.rivieramm.com/opinion/opinion/vesselsvalue-cii-already-impacting-sale-and-purchase-75394 (accessed on 5 September 2024).
11. Wang, S.; Psaraftis, H.N.; Qi, J. Paradox of international maritime organization's carbon intensity indicator. *J. Commun. Transp. Res.* **2021**, *1*, 100005. [CrossRef]
12. Kim, H.; Yeo, S.; Lee, J.; Lee, W. Proposal and analysis for effective implementation of new measures to reduce the operational carbon intensity of ships. *J. Ocean. Eng.* **2023**, *280*, 114827. [CrossRef]
13. Rauca, L.; Batrinca, G. Impact of carbon intensity indicator on the vessels' operation and Analysis of Onboard Operational Measures. *J. Sustain.* **2023**, *15*, 11387. [CrossRef]
14. Masodzadeh, P.G.; Ölçer, A.I.; Ballini, F.; Celis, J.G. Live carbon-tracking mechanism for ships, a methodology to mitigate uncertainties in the carbon intensity calculations. *Transp. Res. Interdiscip. Perspect.* **2024**, *23*, 101004. [CrossRef]
15. Díaz-Secades, L.A. Enhancement of maritime sector decarbonization through the integration of fishing vessels into IMO energy efficiency measures. *J. Mar. Sci. Eng.* **2024**, *12*, 663. [CrossRef]
16. IMO. *2022 Guidelines on the Reference Lines for Use with Operational Carbon Intensity Indicators (CII Reference Lines Guidelines, G2) (Resolution MEPC.353(78))*; International Maritime Organization: London, UK, 2022.
17. IMO. *2021 Guidelines on the Operational Carbon Intensity Reduction Factors Relative to Reference Lines (CII Reduction Factors Guidelines, G3) (Resolution MEPC.338(76))*; International Maritime Organization: London, UK, 2021.
18. IMO. *2022 Interim Guidelines on Correction Factors and Voyage Adjustments for CII Calculations (CII Guidelines, G5) (Resolution MEPC.355(78))*; International Maritime Organization: London, UK, 2022.
19. Daniel, H.; Trovão JP, F.; Williams, D. Shore power as a first step toward shipping decarbonization and related policy impact on a dry bulk cargo carrier. *eTransportation* **2022**, *11*, 100150. [CrossRef]
20. Radwan, M.E.; Chen, J.; Wan, Z.; Zheng, T.; Hua, C.; Huang, X. Critical barriers to the introduction of shore power supply for green port development: Case of Djibouti container terminals. *Clean Technol. Environ. Policy* **2019**, *21*, 1293–1306. [CrossRef]
21. European Union. Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the Use of Renewable and Low-Carbon Fuels in Maritime Transport, and Amending Directive 2009/16/EC. 2023. Available online: https://eur-lex.europa.eu/eli/reg/2023/1805/oj (accessed on 5 September 2024).

22. IMO. *Analysis for Effective Implementation of New Measures to Reduce the Operational Carbon Intensity of Ships (MEPC 80/INF.28)*; International Maritime Organization: London, UK, 2023.
23. IMO. *2021 Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI and EEXI (MEPC.1/Circ.896)*; International Maritime Organization: London, UK, 2021.
24. IMO. Just in Time Arrival Guide Issued to Support Smarter, More Efficient Shipping 2020. Available online: https://imo-newsroom.prgloo.com/news/just-in-time-arrival-guide-issued-to-support-smarter-more-efficient-shipping (accessed on 5 September 2024).
25. IMO. *Invitation to Member States to Encourage Voluntary Cooperation Between the Port and Shipping Sectors to Contribute to Reducing GHG Emissions from Ships (Resolution MEPC.366(79))*; International Maritime Organization: London, UK, 2022.
26. Dujmović, J.; Bernečić, D. Deviations and Errors Review on Measuring and Calculating Heavy Fuel Oil Consumption and Fuel Stock Onboard Vessels Equipped with Volumetric Fuel Consumption Flowmeters. *Sci. J. Marit. Res.* **2021**, *35*, 297–307. Available online: https://pdfs.semanticscholar.org/d2d7/174abd6030ec5089b3c5bda19c4704c39437.pdf (accessed on 5 September 2024). [CrossRef]
27. DNV. Biofuels in Shipping 2023. Available online: https://energycentral.com/system/files/ece/nodes/612579/dnv_biofuels_in_shipping_white_paper_final.pdf (accessed on 5 September 2024).
28. BIMCO. CII Operations Clause for Time Charter Parties 2022. 2022. Available online: https://www.bimco.org/contracts-and-clauses/bimco-clauses/current/cii-operations-clause-2022 (accessed on 5 September 2024).
29. BIMCO. CII Clause for Voyage Charter Parties 2023. 2023. Available online: https://www.bimco.org/contracts-and-clauses/bimco-clauses/current/cii-clause-for-voyage-charter-parties-2023 (accessed on 5 September 2024).
30. coZEV. Amazon, Electrolux, Philips, and Over 20 Other Major Global Companies Launch Historic Tender to Accelerate Deployment of Zero-Emission Shipping, 2023. Available online: https://www.cozev.org/thelatest/amazon-electrolux-philips-and-over-20-other-major-global-companies-launch-historic-tender-to-accelerate-deployment-of-zero-emission-shipping (accessed on 5 September 2024).