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Possibilities of Fulfillment and Consequences of Introducing the Carbon Intensity Indicator in International Shipping

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Abstract: Maritime transport contributes to stimulating the development of civilisation. According to the European Environment Agency, around 1/4 of the total CO_2 emissions in the EU in 2019 came from the transport sector, of which 71.7% were from road transport. The share of CO_2 emissions from maritime transport is estimated to be about 3% of the world's. In terms of energy demand for moving a specific load over a specific distance, it is currently the cheapest form of transport. The International Maritime Organization's activities aim to reduce the environmental impact of this form of transport. The article discusses the expected effects of the regulations introduced until 2023. Regulations have a significant impact on the increase in transport costs. There may be far-reaching changes in the shipping market that have an indirect (rather unintended) effect due to the introduced regulations. "Side effects" can be very severe, especially for shipowners with a small number of ships. The article attempts to draw attention to such threats.

Keywords: IMO regulations, ship operation, climate targets, energy efficiency indicators, environment protection, greenhouse gases

1. Introduction

In 2023, the International Maritime Organization's (IMO) regulation on the Energy Efficiency for Existing Ships (EEXI) and the Carbon Intensity Indicator (CII) entered into force as part of the IMO's short-term climate targets with the requirement to comply with them at the end of this year (IMO 2023a). Earlier, in 2013, regulations for determining the Energy Efficiency Design Index (EEDI) of a ship under construction came into force along with the fulfilment of limit limits for a given type of ship and its deadweight, and then a non-obligatory determination of the Energy Efficiency Operational Index of a ship in operation (EEOI) (IMO 2023b, IMO 2023c, IMO 2023 d, IMO 2023e, PRS 2023, Parker et al. 2015), and from 1 January 2023 also for ships already previously in operation, which falls under the regulation, attained Energy Efficiency Existing Ship Index (EEXI). From 1 January 2023, it will be mandatory for all ships to calculate their attained EEXI to measure their energy efficiency and to initiate data collection to report their annual operational carbon intensity indicator (CII) and CII rating.

The introduced regulations force shipowners to take several actions that will improve the EEXI and CII indicators in the coming years, and thanks to this, further operation of these ships will be possible. In the event of failure to comply with the imposed requirements, the shipowner will be forced to take modernisation measures or discontinue the ship's operation.

As a stimulus to reduce carbon intensity (equivalent carbon dioxide emission) of all ships by 40% by 2030 compared to the 2008 baseline, ships will be required to calculate two ratings:

- their attained Energy Existing Ship Index (EEXI) to determine their energy efficiency,
- their annual operational Carbon Intensity Indicator (CII) and associated CII rating – carbon intensity links the GHG emissions to the amount of cargo carried over the distance travelled (IMO 2023a).

2. Materials and Methods

The article uses the regulations introduced by the IMO and additional requirements regarding greenhouse gas emissions into the atmosphere imposed by the European Union Parliament. They were analysed in terms of the potential effects on maritime transport. Considerations were made regarding the formulation of assumptions and design requirements for newly built ships from the point of view of the shipowner and the introduction of necessary changes in the fuel system or the power system of already built ships in the perspective of their further operation until and after 2030. Due to the variety of suggested changes and the significant costs of their implementation, there is an urgent need for shipowners to carry out analyses in the context of the age and type of the ship, its size, prospects for its further operation and to estimate the necessary financial outlays

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to adjust the ship's energy efficiency indicators to the imposed limits. Particular attention was paid to the Carbon Intensity Indicator (CII). Basic options that could meet these limits were analysed.

3. Results

3.1. Ship's power plant energy efficiency

At the end of the 20th century, the most important indicator of a ship's power plant energy efficiency was the thermal efficiency of power plant equipment, mainly the main engine, auxiliary engines and steam boilers. The energy efficiency index of the power plant was determined. In the case of the construction of deep utilisation of waste heat systems and their use, the efficiency exceeded 60%. The activities aimed to reduce the total fuel consumption. It was followed by activities related to optimising the hull's shape and reducing swimming resistance. With the year 2000, changes began. First, related to the restrictions on nitrogen oxide emissions from ship engines introduced by the IMO, and then the emission limits for sulfur oxides, hydrocarbons and particulate matter (IMO 2023d). Carbon dioxide emissions were not limited, and it should be noted that systems reducing the emission of harmful substances into the atmosphere from ship engines reduced their efficiency and nominal power. According to the IMO regulations, the negative effects of these systems' operation were limited to a decrease in efficiency by 1% and power by 2%. In fact, they were much larger, reaching a 5-10% increase in energy demand and operating costs of these systems (ABS 2017, Chang & Wang 2014). As a result, using these systems caused a proportional increase in fuel consumption and increased carbon dioxide emissions in the same percentage. From 1 January 2013, the requirement to determine the Energy Efficiency Index of the Designed Ship (EEDI) was introduced, and the limits of this indicator were specified, which was to be reduced by 5-10% every 5 years, depending on the type and size of the ship. An example of such limits and their planned reductions is presented in Table 1.

According to Annex VI Regulation 24 of IMO's MARPOL 73/78 Convention (IM 2005), the required EEDI should be determined according to equation 1.

$$\text{Attained EEDI} \leq \text{Required EEDI} = \left(1 - \frac{X}{100}\right) \cdot \text{Reference line value} \tag{1}$$

where X is the reduction factor specified in Table 1 for the required EEDI compared to the EEDI reference line.

Table 1. EEDI reduction factors (X) relative to the EEDI reference line expressed as a percentage required after 2020 – selected examples (DNV 2023, IMO 2023a, IMO 2023b)

Ship type	Size	Phase 2 1st January 2020 – 31st December 2024	Phase 3 1 January 2022 and onwards	Phase 3 1 January 2025 and onwards
Bulk carrier	20,000 DWT and above	20		30
	10,000 and above but less than 20,000 DWT	0-20*		0-30*
General Cargo ships	15,000 DWT and above		30	
	3,000 and above but less than 15,000 DWT		0-30*	
LNG carrier	10,000 DWT and above		30	
Container vessel	200,000 DWT and above		50	
	120,000 and above but less than 200,000 DWT		45	
	80,000 and above but less than 120,000 DWT		40	
	40,000 and above but less than 80,000 DWT		35	
	15,000 and above but less than 40,000		30	
	10,000 and above but less than 15,000 DWT		0-30*	

*Reduction factor to be linearly interpolated between the two values dependent upon ship size. The lower value of the reduction factor is to be applied to the smaller ship size.

The reference line values shall be calculated as follows:

$$\text{Reference line value} = a \cdot b^{-c} \tag{2}$$

where a, b and c are the parameters given in Table 2.

Table 2. Parameters for the determination of the reference values for the different ship types – selected examples (IMO 2023a, IMO 2023b)

Ship type defined in Regulation 2	a	b	c
Bulk carrier	961.79	DWT of the ship where DWT <= 279,000 279,000 where DWT > 279,000	0.477
General Cargo ship	107.48	DWT of the ship	0.216
LNG carrier	2,253.7	DWT of the ship	0.474
Containership	174.22	DWT of the ship	0.201
Tanker	1,218.80	DWT of the ship	0.488

This indicator could be achieved if the ship was operated following the design assumptions. Changing the operating speed of a ship drastically changes the power demand for ship propulsion, which makes it difficult to use and reduces the efficiency of waste heat utilisation systems. In addition, not all systems were started (this requires time to start them at a certain load of the main engine, and at the same time, there are problems with their rational use – due to the inability to store excess energy).

As a result of the development of systems increasing the energy efficiency of the power plant engines, significant investment costs were incurred to meet the EEDI indicator. Then in many operational states of the ship, there were problems with their effective use, which resulted in the fact that the actual energy efficiency indicator of the ship changed over time. Most of the operational states were above the design index.

3.2. Ship energy efficiency indicators and their limits

After the end of calendar year 2023 and after the end of each following calendar year, each ship of 5,000 gross tonnage and above which falls into one or more of the categories in regulations of Annex VI shall calculate the attained annual operational CII over 12 months from 1 January to 31 December for the preceding calendar year, using the data collected following Regulation 27 of this Annex, taking into account the guidelines to be developed by the IMO (IMO 2023d).

The required annual operational CII shall be determined as follows:

$$\text{Required annual operational CII} = \left(1 - \frac{Z}{100}\right) \cdot \mathrm{CII_R} \tag{3}$$

where Z is the annual reduction factor to ensure continuous improvement of the ship's operational carbon intensity within a specific rating level, and $\mathrm{CII_R}$ is the reference value.

The attained annual operational CII shall be documented and verified against the required annual operational CII to determine operational carbon intensity rating A, B, C, D or E, indicating a major superior, minor superior, moderate, minor inferior, or inferior performance level, either by the Administration or by any organisation duly authorised by it, taking into account the guidelines developed by the IMO. The middle point of rating level C shall be the value equivalent to the required annual operational CII set out in paragraph 4 of this regulation. A ship rated as D for three consecutive years or rated as E shall develop a plan of corrective actions to achieve the required annual operational CII. The shipowner is forced to take action to improve this indicator to a minimum rating C. Action should include a review of the SEEMP to find ways to achieve a better rating accordingly, considering the guidelines to be developed by the IMO or Maritime Organization. The revised SEEMP shall be submitted to the Administration or any organisation duly authorised by it for verification, preferably together with, but in no case later than 1 month after reporting the attained annual operational CII following paragraph 2 of this regulation.

A review shall be completed by 1 January 2026 by the IMO to assess (IMO 2023b):

- the effectiveness of this regulation in reducing the carbon intensity of international shipping,
- the need for reinforced corrective actions or other means of remedy, including possible additional EEXI requirements,
- the need for enhancement of the enforcement mechanism,
- the need for enhancement of the data collection system,
- the revision of the Z factor and $\mathrm{CII_R}$ values.

3.3. Possibility of fulfilment CII regulation

The introduction of regulations applicable to international shipping is very simple. It requires the consent of a certain number of states (usually 50), members of the IMO representing the total tonnage of ships flying their flags at the level of at least 35% of the world's tonnage. The introduction of CII essentially forces shipowners to modernise ship power systems. Even several different types of actions (anti-fouling paints, more frequent washing of the hull, optimisation of the voyage route, better voyage planning – shorter stops in ports) undertaken simultaneously may not improve this indicator.

The basic actions that give hope for improving the index to a level that will raise the category, at least to C, are (IRENA 2023):

- switch to carbon-free fuels with lower carbon content in the molecule or biofuels,
- use of renewable energy (photovoltaics, Flettner rotors, sails), reducing the demand for energy from the basic energy system,
- replacing the elements of the energy system with more efficient ones,
- reducing the ship's service speed,
- batteries of electricity charged from the land grid,
- other, which may potentially be recognised by the maritime administration of the state as meeting the requirements.

3.4. Consequences of introduction CII regulation

The simplest action that gives a chance to significantly improve the indicator and maintain categories A and B in the coming years is to switch to biofuels (e.g. bio-methanol, bio-ethanol, bio-diesel, FAME), which require adaptation of the fuel installation of the engines and their operation on these fuels. Modernisation costs may be acceptable to shipowners, but the main problem will be the availability of these fuels in ports. If a given port has the appropriate infrastructure for bunkering biofuels, then ships that sail close to this port or call at this port regularly may be an incentive to decide on this form of modernisation. An important role will be played by the price of biofuel in energy equivalent concerning petroleum fuels (IRENA 2022a, IRENA 2022b).

Switching to biomethane (bio-LNG) makes sense in the ship design phase. The energy system and the required operational safety systems must be adapted to this type of fuel. Currently, dual-fuel engines should be used to switch to a different liquid fuel (diesel oil, biodiesel) in emergencies. This results in the complication of the fuel system and the need to increase the space for fuel tanks, in addition to bio-LNG, also for liquid fuels (used in the amount of 15% as a pilot dose before methane is fed or injected). Of carbon-free fuels, ammonia is considered. The use of this fuel in marine engines has been positively verified. There is hope for disseminating this type of fuel – in the port of Singapore in 2023, it is possible to bunker ammonia as a ship fuel. The availability of this fuel in many ports of the world and its price in energy equivalent (LHV for diesel oil is 42 MJ/kg and for ammonia 18 MJ/kg respectively) remains an open question.

It is possible to support the ship's energy system with renewable energy obtained on board. The basic problem is the ability to generate energy from these sources so that their share is over 10%, and preferably about 50% of the current demand for energy by the ship. Currently, 1-5% shares are obtained, which is too small a value for obtaining higher CII categories.

Replacing the elements of the ship's power system (engines and boilers) with more thermally efficient ones to increase the engine room's overall efficiency is possible and sometimes used. It applies mainly to those devices that need to be replaced due to their technical condition. Benefits resulting from the use of more modern and more efficient devices reach the value of 1-10%, which may be an unsatisfactory result to improve the CII category. Conversion of the drive system from steam turbines to combustion engines significantly improves the indicators. The increase in efficiency reaches 30-60% of the original value, is well received by the maritime administration, and improves all ship energy efficiency indicators, but will not necessarily be taken into account in a dozen or so years because the next improvement of these indicators for the new energy system may be minimal. Such actions may only make sense if the vessel is to be operated for at least 10-15 years. It should be noted that major overhauls of engines (under the requirements of classification societies and IMO) require using new elements in the air supply system, combustion process and exhaust gas treatment. Engine manufacturers are responsible for modernising the engines and improving their energy parameters.

Reducing fuel consumption and, consequently, improving emission factors into the atmosphere and energy efficiency is possible by reducing the ship's operating speed. It is related to the resistance characteristics of the ship's hull. The resistance of a displacement hull (a typical ship) depends on the ship's speed to the second power, and therefore the engine load and fuel consumption. Unfortunately, despite its fairly common use, it has a basic disadvantage – it extends the cruise's time and all the associated costs. Systems limiting the power of the main engine have been introduced, which leads to limiting the ship's speed depending, for example, on the state of the sea. These are, for example:

- Engine Power Limitation – EPL is a software functionality available as an upgrade of different Digital Governor Systems and other propulsion controls (AutoChief 600, AutoChief C20, CanMan, Helicon X3, Mcon). An important protection is an additional option in the system as the override function allows the operator to exceptionally run the vessel above the pre-defined engine power limit to handle emergencies requiring the use of additional power (to the level of maximum continuous rating) (Kongsberg 2023a);
- Shaft Power Limitation – ShaPoLi is an upgrade of KONGSBERG propulsion control systems. The system automatically limits shaft power not to exceed a pre-set value. It allows the operator to control the vessel's fuel consumption and emission level (Kongsberg 2023b).

The use of electric energy stored in batteries on ships comes down mainly to securing the ship's power system in emergencies, e.g. power failure in the main network. It functions as an uninterruptible power supply. The energy reserve in the batteries reaches the level of 10-1,000 kWh. It is sufficient to provide power to the devices necessary to maintain the ship's safety (GMDSS system), emergency lighting, internal communication, device safety systems, etc. However, it is definitely not enough for the ship's propulsion. As a result, relatively small vessels (below 400 GRT) engaged in short-distance, coastal ferry shipping, e.g. in Norwegian fjords, can use this option. The information from July 2023 shows that a river vessel with the side number N997 is undergoing sea trials in China – a container ship with a carrying capacity of 700 TEU and a length of 120 m, powered by two electric motors with a power of 900 kW in a two-shaft system, may be a swallow for the changes taking place. Electricity is stored in batteries in 36 TEU containers with a total capacity of 50 MWh. It is to ensure the ship's autonomy at a distance of up to 1,100 km.

There are potentially (not defined yet) other options for introducing changes to the ship's energy system, but the maritime administration must approve them of the ship's flag state. The goal for the shipowner is to obtain the minimum category C as the CII indicator and to maintain it in the following years as long as the ship is planned to be operated (IRENA 2023).

4. Final Remarks

The introduction by the IMO of successive indicators of emission of harmful substances into the atmosphere (recently Carbon Intensity Indicator) from ship engines sets out directions for necessary changes in ship operation for shipowners. Decisions must be well thought out to reduce the costs of ship modernisation. The barrier of costs that shipowners can incur prefer the larger ones. The maritime administration of the flag state will greatly impact the necessary modernisation of the ships' power systems and their scope, depending on whether it accepts the modernisations proposed by the shipowner.

There are few opportunities to meet the regulatory requirements. A move away from crude oil-derived fuels in favour of biofuels seems to be a guarantee of success. Of course, as long as biofuels are considered green. More guarantees are provided by switching to carbon-free fuels, e.g. ammonia. These are the trends to be expected in the coming years.

The consequences of introducing new regulations can be serious for international shipping. They require appropriate actions by shipowners, behind which there are significant costs, worsening the economic effects of shipping and consequently lowering competitiveness. The goal of the actions is clear: to reduce the level of emissions and the share of international shipping in global emissions, mainly of carbon dioxide. The final goal is the neutrality of shipping in terms of emissions of harmful substances into the atmosphere (climate neutrality). The next few years will show whether this will be achievable by 2050.

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