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A STUDY ON EEDI AND EEXI REQUIREMENTS AND SHIP EMISSION REDUCTION STRATEGIES

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ABSTRACT

As response to the growing pressure to reduce Green House Gases emissions from ships with detrimental effects on the environment and climate, the International Maritime Organization (IMO) has developed mandatory requirements and regulatory tools such as: Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index (EEXI), Ship Energy Efficiency Management Plan (SEEMP) and Carbon Intensity Indicator (CII). The paper presents o comparative study of EEDI and EEXI requirements, as a set of technical measures to improve ships' energy efficiency and to reduce emissions in line with IMO targets. The paper analyses the specific role of each index and how they together contribute to emissions reduction in the design and construction stages and through operational phases of the ship's life.

Keywords: Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index, (EEXI), ships CO_2 emissions

1. Introduction

The maritime transport sector contributes significantly with approximately 3% to Green House Gas (GHG) emissions, with a detrimental effect on the environment and climate. As response, the International Maritime Organization (IMO) has developed mandatory requirements and regulatory tools such as: Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index (EEXI), Ship Energy Efficiency Management Plan (SEEMP) and Carbon Intensity Indicator (CII), [1], [2], [3], [4].

Each index has distinct aims and applications, leading together to ships' energy efficiency improvement, from newly designed and built ships to those already in service.

The main purpose of this paper is to perform o comparative study of EEDI and EEXI technical requirements, analysing the specific role of each index introduced to decrease ships' emissions in line with IMO targets. EEDI is applied to newly constructed ships from 2013 and EEXI is applied from 2023 to existing ships built prior to EEDI implementation. Both are design indices, based on similar data: deadweight, power, speed, etc. In addition, due to the change of these parameters during ship operation, starting with 2023, IMO has introduced the CII indicator to quantify actual CO2 emissions during navigation [5]. CII requirements and the impact of mandatory operational measures on ships emissions reduction will be a subject for a future study.

The paper analyses the role of each individual index EEDI and EEXI, and at the same time, follows how they contribute together to emissions reduction in the design and construction stages, in different stages of the ship's life. The research analyses the impact of these mandatory requirements on ship design and retrofitting ships.

In the last years, a large part of the research activity carried out in the Research Centre of the Faculty of Naval Architecture of "Dunarea de Jos" University of Galati has been focused on studying the Energy Efficiency Design Index (EEDI) for different types of ships, creating a database and analysing the influence of the propulsion system design on the EEDI improvement. Recently, the study area has been expanded by analysing other design and operation measures established by IMO, in order to reduce ship emissions.

2. IMO Requirements and Regulatory Frameworks for Ships' Emission Reduction

2.1. EEDI Requirements: Overview and Strategies

The Energy Efficiency Design Index (EEDI) represents a mandatory technical measure introduced by the IMO on the 1st of January 2013 for new-build ships [1], [2].

The EEDI is calculated in the design stage for new ships only, with the main aim of designing and building new, less polluting ships with more energy efficient technologies.

EEDI requirements are mandatory for new ships of 400 gross tonnage (GT) and above. It covers multiple "ship types responsible for approximately 85% of CO2 emissions from international shipping" [1] such as: bulk carriers, containerships, tankers, general cargo ships, gas carriers, ro-ro ships, LNG carriers, etc.

EEDI cannot be applied to certain types of ships such as those of less than 400GT, non-commercial vessels (ex. research vessels, offshore support vessels) or ships with non-conventional propulsion systems (ex. gas turbine propulsion, hybrid propulsion systems). It is not applied to existing ships engaged in international voyages that are covered by the Energy Efficiency Existing Ships Index (EEXI) from 2023.

EEDI quantifies the environmental impact of shipping in relation to the benefits to society. It is defined as the ratio of total CO_2 emissions to transport work, expressed in grams of CO_2 emitted per tonne-nautical mile (g CO_2/t·nm). CO_2 emissions are determined by the installed power and the fuel type and consumption. The transport work is given by the ship capacity multiplied with the ship's speed.

The EEDI is calculated based on the ship's design parameters using the following simplified formula (2.1). The formula is more complex for particular situations, including coefficients and corrections factors to adjust the EEDI value [6].

$$EEDI = \frac{PME \cdot CF \cdot SFC \cdot + PAE \cdot CF \cdot SFC}{Ship\ Capacity \cdot Vref} \quad (2.1)$$

where:

- P_{ME}, P_{AE}: Installed power of main and auxiliary engines (kW), determined in ship design stage.
- CF: CO_2 conversion factor (t-CO_2/t-Fuel) depending on the used fuel type. It is a non-dimensional conversion factor between consumed fuel and CO_2 emissions;
- SFC: Specific fuel consumption (g/kWh) defined as amount of fuel use per unit of engine power, being an engine characteristic;
- Ship Capacity: Deadweight (for conventional vessel types), 70% deadweight for containerships, or gross tonnage (for passenger and Ro-Ro ships);
- Vref: Reference Speed [knots] is the ship speed measured at 75% MCR (Maximum Continuous Rating) of the main engine, at the designed ship capacity in summer load line draft and calm water conditions.

For a new ship, the attained EEDI computed with formula (2.1) has to be below the required EEDI.

$$EEDI\ attained \leq EEDI\ required \quad (2.2)$$

The required EEDI is defined by a Reference line value with reduction targets over time, function of the ship type, size and capacity:

$$EEDIreq = (1 - x)Refline = (1 - \frac{x}{100}) \cdot a \cdot b^{-c} \qquad (2.3)$$

EEDI requirements became progressively stricter over time and they have been implemented in phases:
-Phase 0: 2013-2015 (reference line x=0)
-Phase 1: 2015-2019 (reduction x=10%)
-Phase 2: 2020-2024 (reduction x=20%)
-Phase 3: 2025 onwards (reduction x ≥30%).

The applicability of EEDI requirements influences the design and construction of new ships. To comply with EEDI requirements, ships must be designed to operate with high propulsive efficiency and minimal fuel consumption. This can be achieved through reducing ship speed and power, by optimization of hull and propeller design, promoting less pollution technologies, adopting energy saving devices and innovative propulsion systems, etc. Depending on their proven effectiveness and adoption in the industry, some solutions and technologies applied to reduce ships' emissions are considered mature (proven, with high adoption), some are proven with limited adoption or are new or poorly tested (non-mature) [7].

Reducing ship speed is an effective solution to reduce EEDI. Analysing strictly mathematical the EEDI formula, to reduce the fraction value, it is necessary to reduce the numerator (power, fuel) or increase the denominator (ship capacity x speed). In reality, in practice, increasing speed increases power cubically, which mathematically raises the numerator, making difficult the EEDI reduction. Similarly, increased ship capacity requires more power. Reducing ship speed during the design stage is a common solution for lowering EEDI by reducing the required engine power and fuel consumption. By selecting a moderate design speed and optimizing hull and propulsion system, a naval architect has to balance the mathematical formula with physical reality, to effectively reduce EEDI, without sacrificing operational efficiency.

In recent years, the Research Centre of the Faculty of Naval Architecture of Galati has focused on studying the EEDI for different ship types, developing a database, and analysing how propulsion system design influences EEDI reduction.

A brief example focusing on how reducing power and speed affects the EEDI is presented below. Applying the EEDI simplified formula with initial data for a new 75000 tdw bulk carrier [6], MCR_1=10320 kW, v_1=14.81 knots, the attained EEXI was 4.043 g CO_2/t·nm. By selecting other engine with around 6,7% reduced power (MCR_2=8600 kW) and redesigned new optimal propeller, the new ship's speed has been reduced by 6,5% and the EEDI decreased by 10,7%.

Other approach to reduce emissions is hull design optimization from the hydrodynamic point of view, which aims to achieve ship's shapes to decrease the hydrodynamic resistance and consequently the required power at the desired speed, as well to improve the flow in propeller plane for a higher propulsive efficiency. The hull structural optimization by minimizing excess thickness and incorporating light weights material in non-critical areas, aims to reduce the ship weights, consequently the displacement.

An optimal propeller design can improve propulsive efficiency, reducing the necessary power at the required speed, and implicitly the EEDI. Wake adapted propellers with increased open water efficiency, controllable pitch propeller optimised for different loading condition, blades shape and area to reduce cavitation and unsteady forces, energy saving devices to minimise hull propeller interaction coefficients, all these represent solutions to improve propulsive efficiency and reduce fuel consumption and emissions.

To illustrate the influence of propeller design on EEDI, a brief comparative analysis of the results obtained in the case of designing a propulsion system for a BK 75000tdw [6] is presented below. The results for two case studies have been compared, for two engines with very close powers. By designing propellers at the same design point (PD) and finding an optimal combination between engine power (MCR), revolution rate (n), propeller diameter (D) and propeller open water efficiency ($\eta 0$), a reduction in EEDI has been obtained. For only a 3% reduction in power and designing an efficiency-optimized propeller it resulted 0.3% increase in design speed, 4% increase in propeller efficiency in open water, and 3.6% reduction in EEDI.

Table 1 Comparatives results for two case studies [6] related to the influence of the propeller design on EEDI reduction

Parameter	Case 4	Case 8	
MCR [kW]	10680	10320	3% ⇩
n [rpm]	117	100	14% ⇩
DP (%MCR)	75%	75%	-
V [knots]	14.14	14.19	0,3% ⇧
D [m]	6,34	6.88	8% ⇧
$\eta 0$	0,539	0,563	4% ⇧
EEDI	4,378	4,22	3.6% ⇩

Significant steps in ship emissions reduction can be taken by adopting less pollution technologies, promoting more efficient and low-emission engines such as those using alternative fuels or waste heat recovery, by using energy saving devices or renewable energy integration, etc.

Low carbon or zero-carbon fuels such as: LNG, methanol, hydrogen, biofuels, reduce CO_2 emissions per energy unit and may improve EEDI. Emphasis must be placed on compatibility with existing engines technologies, fuel availability and onboard storage requirements.

The Energy Saving Devices (ESDs) have been put into practice to increase ship propulsive performances, to reduce fuel consumption and implicitly ship emissions. They work according to the principles of reducing propeller's axial and rotational losses, and/or decreasing the wake field values, without increasing ship resistance too much. Some of them: in form of fins, pre-swirl stator, full or partial ducts, are located ahead of the propeller improving the water flow behind the ship hull (pre-swirl devices). Other are placed behind the propeller (post swirl devices): boss cap fins, rudder bulb, etc.

Renewable energy integration may improve overall energy efficiency and reduce fuel consumption and CO_2 emissions by supplementing engine power with renewable sources. Wind-assisted propulsion, such as Flettner rotors or towing sails, uses wind power to provide additional thrust, while solar panels can serve as auxiliary power systems to reduce engine load. These new technologies for ships are not yet fully mature, having few applications and no so much practical operational experience.

If a new ship does not comply with EEDI standards, it will not be certified and will not be allowed to operate in international waters. This, EEDI implementation for new-build ships became a significant part of global strategies to reduce ship emissions, an important key instrument not only in the design of ship propulsion systems but also in the overall design of more energy efficiency ships.

2.2. EEXI Requirements: Overview and Strategies

The Energy Efficiency Existing Ship Index (EEXI) represents a mandatory technical measure introduced by IMO on the 1st of January 2023 for existing ships built prior to Energy Efficiency Design Index (EEDI) implementation [1], [3].

The EEXI is calculated for each existing ships built before January 2013 and for ships which have undergone a major conversion [9]. Its main aim is to establish a minimum energy efficiency standard for old ships, comparable to standards applied for new ships designed and built according to the EEDI criteria.

The EEXI is a retroactive design measure taken to ensure that both old and newly built ships play an important role in achieving GHG's emissions reduction objectives.

The EEXI has to be computed once, for each existing ship in order to obtain an International Energy Efficiency Certificate (IEEC).

EEXI requirements are mandatory for all existing ship of 400 gross tonnage (GT) and above, that are engaged in international voyages. It is applied for the same categories of ships as EEDI: bulk carriers, containerships, tankers, general cargo ships, gas carriers, ro-ro cargo ships, LNG carriers, ro-ro passenger ships, cruise passenger ships, etc. EEXI cannot be applied to ships not engaged in international voyages, warships, fishing vessels, pleasure yachts, etc.

While EEDI sets the energy efficiency standards for new ships, the EEXI extends these standards to the existing ships already in operation. The EEXI is calculated retroactively using the same formula as EEDI, i.e., as ratio of total CO_2 emissions per transport work (g CO_2/t·nm). The EEXI is calculated using parameters similar to EEDI: engines power, fuel type and characteristics, ship capacity, speed, etc. Some of these parameters have slightly different definitions than those used for the EEDI [10], and they may be estimated or calculated based on the ship's actual operational data.

$$EEXI = \frac{PME \cdot CF \cdot \ SFC \ \cdot + PAE \cdot CF \cdot SFC}{Ship\ Capacity \cdot Vref} \quad (2.4)$$

Unlike EEDI, which uses the ship's predicted maximum speed at 75% MCR during the design stage, EEXI uses the actual operational speed of the vessel. This is estimated or calculated at 75% MCR based on available data such as sea trials data, speed–power curves, model tests or CFD simulations.

For the EEDI calculation, the main engine power is based on the Maximum Continuous Rating of the engine at full capacity as designed (75% MCR). For EEXI calculation, the actual engine power used in service is considered: adjusted for operational conditions. (83% of the limited installed power MCRlim or 75% of the original installed power MCR, whichever is lower) [3].

Regarding fuel efficiency and consumption: EEDI uses predicted fuel consumption based on the ship's design and expected performance, while EEXI uses real fuel consumption data from the ship's operations.

The attained/computed EEXI has to be below the required EEXI.

$$EEXI\ attained\ \leq EEXI\ required \quad (2.5)$$

The required EEXI is the same as the required EEDI:

$$EEXIreq = \left(1 - \frac{Y}{100}\right) \cdot EEDI\ Ref\ line \quad (2.6)$$

where Y is a reduction factor for the required EEXI relative to the EEDI reference line, depending of ship size and type [9]. Required EEXI is equivalent to Phase 2 or 3 of EEDI, depending on ship type.

Table 2 Example of reduction factors for the required EEXI relative to the EEDI reference line for different types of commercial ships

Ship type	Size	Y
Bulk carrier	DWT > 200000	15
	20000<DWT<200000	20
	10000<DWT<20000	0-20
Tanker	DWT > 200000	15
	20000<DWT<200000	20
	4000<DWT<20000	0-20
Container-ships	DWT > 200000	50
	120000<DWT<200000	45
	80000<DWT<120000	35
	40000<DWT<80000	30
	15000<DWT<40000	20
	DWT<15000	0-20
LNG carrier	DWT > 10000	30

The applicability of EEXI requirements influences the retrofitting and operation of existing ships, ensuring that ships already in service meet a minimum energy efficiency standard comparable to new ships under the EEDI. The application of EEXI affects how older ships are modified, operated and certified to meet ships emissions reduction targets. To comply with EEXI, existing ships must undergo technical design modifications or implement operational changes such as: limited engine power, shaft generator system using, ship's speed reduction, fuel switching, hull and propeller upgrade, energy saving devices installation, hybrid propulsion systems adoption, etc.

Engine power limitation by restricting maximum output is a proven and widely adopted measure to reduce fuel consumption, CO2 emissions and EEXI improving. Function on the engine type, the required control degree and operational profile, there are several technical solutions for power limitation. Electronic power limitation involves the use of electronic control units to manage parameters such as fuel injection, speed and loading of modern marine engines. No need to modify the engine's structure but the engine may not be able to generate the required power for emergency situations. Mechanical power limitation applied for older engines involves engine's components adjustments. By installing a shaft generator system, the ship's energy efficiency can be improved by 3-5% [12]. A shaft generator uses a part of the main engine power to produce electricity for use onboard. Engine propulsive power limitation is a practical, quick and cost-efficient solution for EEXI improvement, but it limits the ship' speed, which may increase the voyage time, affecting operational efficiency.

Fuel switching entails changing the conventional fuels with lower carbon options like LNG, biofuels, methanol, i.e., to reduce emissions. Its effectiveness requires ship modifications and depends on fuel costs and availability.

Hull and propeller upgrade can improve ship hydrodynamic performances and reduce fuel consumption. Thus, hull cleaning can reduce ship hydrodynamic resistance and necessary propulsive power. Propeller polishing improves propulsive efficiency, reducing fuel consumption and the carbon footprint of marine vessels [11].

Upgrading, redesigning propeller and installing a wake adapted propeller or other propulsion device such as controllable pitch propeller, ducted propeller, may improve propulsive efficiency. By adding pre-swirl and post-swirl devices (fins, ducts, semi-ducts, wake-equalizing duct, boss cap fins, etc.), the overall propulsive efficiency can be increased by improving the flow into propeller plane and recovering the energy lost in propeller stream.

Ship's speed reduction is a practical solution for reducing fuel consumption and ship emissions ensuring IMO requirements compliance. A brief analysis, focusing on the power speed relationship and how reducing these parameters affects the EEXI values, is presented below by a short mathematical calculation. The necessary propulsive power is generally proportional to the cube of ship's speed: $P \propto v^3$. Applying the EEXI simplified formula with initial data for a 50000 tdw vessel, P_1=8000 kW, v_1=15 knots, SFC=190 g/kWh and CF=3,114 t-CO_2/t-Fuel, the attained EEXI is 6.31 g CO_2/t·nm. By reducing velocity at v_2=13 knots, the power decreases based on cube low, and the result will be: attained EEXI = 4.74 g CO_2/t·nm, resulting around 25% EEXI's reduction.

Speed reduction may be easy to implement through technical and operational practices but it can lead to longer voyage durations, potentially causing delays and affecting fleet productivity. Therefore, it is important to balance speed reduction for CO_2 emissions requirements with operational expectation.

Speed reduction can be implemented by an operational management too, involving: slow steaming by reducing cruising speed, voyage planning by optimizing route and the use of speed optimization software. To quantify the actual CO2 emissions during navigation [5], IMO has introduced as operational regulatory the Carbon Intensity Indicator (CII), to measure the ship's actual CO_2 emissions per transport work over a year. The CII requirements and the impact of mandatory operational measures on ship emission reduction will be the subject for a future study. A comparative study on EEXI and CII requirements will be useful to understand that EEXI assesses an existing ship's potential efficiency based on design, while CII evaluates the ship's real operational carbon intensity over time.

The EEDI implementation impacts existing ships by encouraging technical upgrades and regulatory compliance, supporting the transition to low- and zero- carbon shipping.

3. EEDI vs EEXI: Comparative Summary and Discussion

The study has focused on the requirements and the roles of indices EEDI and EEXI, and on examining their contribution to emissions reduction throughout a ship's life cycle, from design to retrofitting phases. It presents solutions for implementing the requirements of each index and highlights the similarities and differences between the technical design measures aimed to decrease gas emissions.

The EEDI has been introduced by the IMO in 2013 for new-build ships, while the EEXI is mandatory from 2023, for existing ships built prior to EEDI implementation.

The EEDI is calculated in the design stage for new ships only, with the main aim of designing and building new, less polluting ships with more energy efficient technologies. The EEXI purpose is to establish a minimum energy efficiency standard for old ships, comparable to the standards applied for new ships designed and built according to the EEDI criteria.

The types of vessels are generally the same: ships of 400 gross tonnage (GT) and above such as: bulk carriers, tankers, containerships, gas carrier, but EEDI is applied to new-build ships, while EEXI is applied to existing ones.

Both EEDI and EEXI are calculated with the same formula as the total CO_2 emissions over to transport work, being expressed in grams of CO_2 emitted per tonne-nautical mile (g CO_2/t·nm). CO_2 emissions are calculated based on engines power and fuel characteristics (type and consumption). The transport work is given by the ship capacity multiplied with ship's speed. Some of these parameters for EEXI have slightly different definitions than those used for EEDI [10]: for EEDI the design parameters are used, for EEXI some parameters may be estimated or calculated based on the ship's actual operational data such as: sea trials data, speed–power curves, model tests or CFD simulations.

The attained energy indices (EEDI and EEXI) have to be below the required values. The required EEDI is defined by a Reference line value with reduction targets over time, in 4 phases, function of the ship type, size and capacity. The required EEXI is the same with the required EEDI, being equivalent to Phase 2 or 3 of EEDI, depending on ship type.

The EEDI is computed once, at new ship design and construction. The EEXI is computed once, for existing ships built prior to EEDI implementation or for ships which have undergone a major conversion, for certification. For every ship that complies with IMO requirements (EEDI/EEXI), an International Energy Efficiency Certificate is issued by Flag Administration, a classification society. The process involves technical files, verification of the accuracy of initial data, calculating and comparing the attained index (EEXI and/or EEDI) with the required values.

In this paper, the EEDI study includes a brief calculation based on real data previously obtained from designing ship propulsion system for various commercial ships, as part the research activity carried out at the Faculty of Naval Architecture of Galati. In contrast, the EEXI analysis presents only a simplified mathematical calculation based on the known formula and the power-speed law.

EEDI improvements for new ships can be achieved, by optimization hull and propeller design, reducing ship speed and power, promoting less pollution technologies, adopting energy saving devices and innovative propulsion systems, etc. Existing ships can comply with EEXI through technical design modifications and upgrades such as: limited engine power, shaft generator system using, ship's speed reduction, fuel switching, hull and propeller upgrade, energy saving devices installation, hybrid propulsion systems adoption, etc.

A brief comparison regarding EEDI and EEXI requirements (EEDI vs. EEXI [14]) is presented in Table 3.

Table 3 Comparative and summary study: EEDI versus EEXI

Regulation	EEDI	EEXI
Full name	Energy Efficiency Design Index	Energy Efficiency Existing Ship Index
Measure Type	Technical measure - Design Index	Technical measure - Design Index
Applies From	2013	2023
Regulatory basis	IMO MARPOL Annex VI – Regulation 20 (adopted under MEPC.203(62) in 2011)	IMO MARPOL Annex VI – Regulation 23 (introduced by MEPC.328(76) in 2021)
Applies To	New ships (built from 2013 onwards), New Ships ≥400GT	Existing Ships (built before 2013) Old Ships ≥400GT
Objectives	To design and build new ships with increased energy efficiency	To align existing ships with IMO CO_2 emissions reduction targets
Calculation basis	total CO_2 emissions over transport work	total CO_2 emissions over transport work
Unit of measure	g CO_2/t·nm	g CO_2/t·nm
Calculation formula	$EEDI = \frac{PME \cdot CF \cdot SFC \ \cdot + PAE \cdot CF \cdot SFC}{Ship\ Capacity \cdot Vref}$	$EEXI = \frac{PME \cdot CF \cdot SFC \ \cdot + PAE \cdot CF \cdot SFC}{Ship\ Capacity \cdot Vref}$
Computational data	Main and auxiliary engines powers, ship capacity, design speed, fuel quality and quantity data	Similar to EEDI. Some of parameters have slightly different definitions than those used for the EEDI
Requirements	$EEDI\ attained \ \leq EEDI\ required$	$EEXI\ attained \ \leq EEXI\ required$
Required Index formula	$EEDIreq = (1 - \frac{x}{100}) \cdot Refline$	$EEXIreq = \left(1 - \frac{Y}{100}\right) \cdot EEDI\ Ref\ line$
Requirements over time	EEDI requirements have been implemented in Phases 0,1,2,3	Required EEXI is equivalent to Phase 2 or 3 of EEDI, depending on ship type
Verification/ Certification	Once - at ship construction	One time after Jan. 2023, or after the ship has undergone a major conversion
Compliance strategy	Ship hull and propulsion system design optimization	Retrofitting, engine power limitation, speed reduction

4. Conclusions

The maritime transport sector contributes approximately 3% of the global Green House Gas (GHG) emissions, impacting the environment and climate. In response, the International Maritime Organization (IMO) has introduced mandatory technical and operational measures including EEDI, EEXI, SEEMP and CII, each with specific objectives and applications, improving together the energy efficiency of newly designed and built ships and existing ships, too.

In the last years, a large part of the research activity carried out in the Research Centre of the Faculty of Naval Architecture of "Dunarea de Jos" University of Galati has focused on studying the Energy Efficiency Design Index (EEDI) for different types of ships, creating a database and analysing the influence of the propulsion system design on the EEDI reduction. Recently, the study area has been expanded by analysing other design and operation measures established by IMO, in order to reduce ship emissions.

The main purpose of the paper was to perform o comparative study of EEDI and EEXI technical requirements, analysing the specific role of each index, calculation methods and necessary initial data, mandatory requirements and improvement solutions. EEDI and EEXI are both design indices, based on similar data: deadweight, power, speed, etc. The present work analysed the impact of these mandatory requirements on ship design and retrofitting ships.

Aspects regarding the effects of reducing ship speed and installed engine power on the improvement of energy efficiency indices, have been analysed through calculation examples and the results obtained.

Technical solutions to enhance the energy efficiency of both newly designed ships and those existing in operation have been reviewed. Ship speed and power reduction, hull and propeller optimization, less polluting equipment and technologies, energy saving devices and innovative propulsion systems can help reduce ships emissions to comply with the IMO targets.

Futures research will focus on analysing different EEXI case studies for various types of ships, in order to create a database that allows for the study of the influence of certain parameters on improving EEDI and reducing emissions. Finding an answer to the question of how useful a statistical analysis of the databases created for the EEDI and EEXI results of the studied ships would be a topic of future investigations. CII requirements and the impact of mandatory operational measures on ship emission reduction will be a subject for a future work.

As part of ships emission reduction strategy, IMO requirements aim to reduce CO_2 emissions by 40% by 2030 from 2008 level, achieving zero GHG emissions by around 2050 [1].

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