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Impact of Energy Efficiency Design Index on Ship Design and Operation

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ABSTRACT: Reducing operating cost from the design phase, and cost-efficient operation still remain the most important consideration in shipping as every ship-owner tries to maximize profit. This research evaluated the impact of Energy Efficiency Design Index (EEDI) on ship design and operation, with emphasis on the various methods for cost-efficient operation from both technical, and operational perspectives. The different parameters that influence the EEDI of ships were investigated using specific ship energy efficiency data. Saavedra-Tide vessel was used as a case study to determine the extent to which fuel-savings could be influenced by ship speed, deadweight, etc. The Energy Efficiency Operational Indicator (EEOI) tool was employed to analyse the amount of fuel consumed at sea, and at ports. The analysis was based on the voyage report sheet extracted from the vessel's log book. The results from the Saavedra-Tide voyages revealed that EEOI values were lower at lower ship speeds than at higher ship speeds. A 10% reduction in ship speed produced 20% reduction in EEOI. Similarly, when the fuel consumption was at 6 tonnes, the vessel recorded EEOI value of 1.834×10^{-4} tonnes CO_2/tonne-mile. While at fuel consumption of 6.8 tonnes, EEOI value rose to 2.142×10^{-4} tonnes CO_2/tonne-mile. This implied that fuel oil consumption was more effective at cruise speeds than at higher speeds. In conclusion, a strict compliance of the EEDI regulations proposed by this study would significantly reduce fuel consumption which could cutdown on the huge costs of voyages, even though the implementation would have an initial high capital investment in better ship design and machinery.

KEYWORDS: Energy Efficiency, Ship Design, MATLAB, Impact, Operation

I. INTRODUCTION

Maritime transport is still the backbone of global transport due to its large trade volume, and low unit transportation cost. About 80 percent of global trade by volume and over 70 percent of global trade by value are carried by sea and are handled by ports worldwide (UNCTAD, 2018). Thus, International Maritime Organization (IMO) considers it imperative to reduce the impact of shipping on climate change by implementing regulatory measures in July 2011, making the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) mandatory for new ships and all ships above 400 GRT respectively (**IMO, 2011**).

The EEDI is the measure of total CO_2 emission per tonne mile. The amount of CO_2 emitted depends on fuel consumption. While fuel consumption depends on the total power requirement. This implies that the EEDI formulation eventually has certain impact on ship design parameters which are closely related to the economic performance of the ship. The EEDI requires a minimum energy efficiency level in terms of CO_2 emissions per capacity mile for different ship type and size segments (**IMO, 2009**). Due to these regulations, ship design is required to get affected and any changes to basic design features such as speed and deadweight have an impact on shipping economics. There are various measures which can be used to meet EEDI requirements. It is particularly important to study financial and economic impacts of EEDI regulations on ship owners and charterers, because ship owners, and charterers operate in the industry to maximize their profits out of the shipping business, and any negative impact of these regulations on ship's earning potentials may put them out of the business.

The EEDI requires a specified energy efficiency that could be primarily, expressed by fuel consumption per capacity mile (e.g., tonne per mile) for different ship types and sizes (**Hon & Wang, 2019**). With the level being tightened over time, the EEDI will stimulate continued technical development of all the components influencing the energy efficiency of a ship. In order to meet the energy efficiency design index (EEDI) regulations, a ship builder strives to reduce the EEDI value. This can be done in different ways which include,

i. The reduction of individual emissions of main engine, auxiliary engine, and shaft generator/motor.
ii. By using efficient technologies such as shaft generator, and waste heat recovery (WHR) system that will reduce the amount of CO_2 emissions in the atmosphere. Hence, improving energy efficiency.
iii. By increasing ship's cargo carrying capacity.

Concept of EEDI

The ship "EEDI" has been formulated by the IMO's Marine Environment Protection Committee (MEPC) as a measure of the CO_2 emission performance of ships. The EEDI requires a specified energy efficiency that could be primarily, expressed by fuel consumption per capacity mile (e.g., tonne-mile) for different ship types and sizes. With the level being tightened over time, the EEDI will stimulate continued technical development of all the components influencing the energy efficiency of a ship. Reduction factors are set until 2025 when a 30% reduction is mandated over the average efficiency for ships built between 1999 and 2009. The EEDI has been developed for the largest and most energy intensive segments of the world merchant fleet, and will embrace about 70% of emissions from new oil and gas tankers, bulk carriers, general cargo, refrigerated cargo and container ships as well as combination carriers (wet/dry bulk) – as shown in Fig 1.

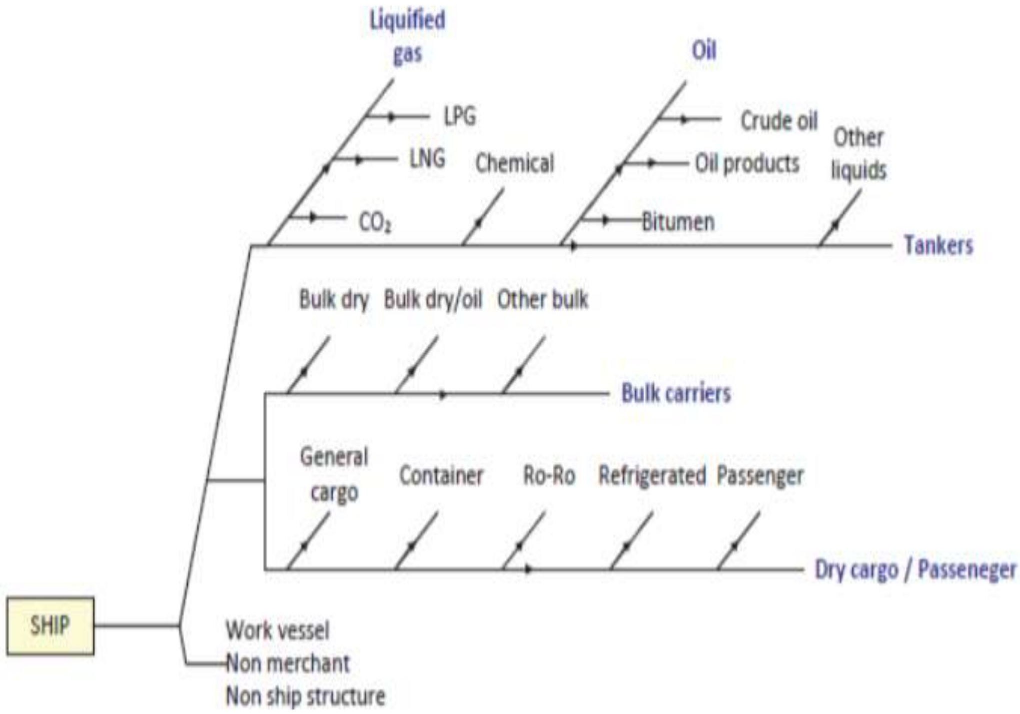

Fig 1: A graphical representation of cargo carrying vessels implementing EEDI (Tadeus, et al., 2012)

II. METHODOLOGY

This research tries to estimate the impact of energy efficiency design and operational index on ship design and operation from the operational perspective of EEDI. The materials used to investigate the impact of energy efficiency design index on ship and operation are based on the data obtained from a case study offshore supply vessel, Saavedra Tide with four-stroke marine diesel diesel-electric. The ship voyage report data takes into account all voyages completed between June 2017, and November 2019.

The data include: voyage speed, voyage distance, fuel consumption, cargo weight, and voyage duration. The ship uses only marine diesel oil (MDO). The carbon conversion factor (C_f) for MDO was selected as stipulated in MEPC.1/circ/684 ANNEX. Tables 2, and 3 presents extractions from data used for this research.

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To investigate the impact of EEOI on variable ship speed, and fuel consumption, voyage parameters were selected for a specific voyage route (Onne-Akpo field), at different operating ship speed. Also, in order to analyse the impact of CO_2 emissions on repeated ship speeds, the voyage parameters were selected for a repeated ship speed (6knots), and voyage route (Egina-Akpo field). MATLAB application was employed to carry out the EEOI analysis of the data obtained from the case study vessel in order to investigate the impact of ship speed on fuel consumption, and carbon emissions.

Calculation of Energy Efficiency Operational Indicator (EEOI) Based on Operational Data

To compute EEOI values using the standard method specified in marine environmental committee (MEPC) guidelines for energy efficiency calculations, voyages of Saavedra Tide taken between 2017 and 2019 were selected from two voyage routes of the ship. The voyage duration includes stops at anchorages, and ports. Voyages with similar cargo weight were carefully selected to ascertain the effect of changing ship speeds during operation. This study also investigates the relationship between fuel oil consumption, voyage duration, and ship speeds to enable ship owners achieve more fuel savings from their daily ship operations.

The basic expression for EEOI for a voyage is defined as:

$$EEOI = \frac{\sum_{J} FC_{J} \ X \ C_{Fj}}{m_{cargo} \ x \ D}$$

Where average of the indicator for a period or for a number of voyages is obtained, the indicator is calculated as:

$$Average \ EEOI = \frac{\sum_{i}\sum_{j}\left(FC_{IJ} \ x \, C_{Fj}\right)}{\sum_{i}(m_{cargo,i} \ x \ D_{i})}$$

Where:
j` = the fuel type;
i = the voyage number;
FCij = the mass of consumed fuel j at voyage i;

CFj = the fuel mass to CO_2mass conversion factor for fuel j;
Mcargo = cargo carried (tonnes) or work done (Number of TEU or passengers) or gross tonnes for passenger ships; and
D = the distance in nautical miles corresponding to the cargo carried or work done.

The unit of EEOI depends on the measurement of cargo carried or work done, e.g., tonnes CO2/ (tonnes • nautical miles), tonnes CO2/ (TEU • nautical miles), tonnes CO2/ (person • nautical miles), etc.

Table 1: Reference value of CF for different fuel type

TYPE OF FUEL	Reference	Carbon Content	C_F (t-CO2/t-Fuel
1. Diesel/Gas	Oil ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400

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4. Liquefied Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquefied Natural Gas (LNG)		0.75	2.750000

Table 1 shows the conversion factor for different fuel types. CF is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content.

Table 2: Ships Voyage Report Sheet for Onne-Akpo field

NAME OF VESSEL: Saavedra Tide						
Voyage Period	**Speed (knots)**	**Voyage Distance**	**Cargo Weight**	**Voyage Duration (hrs)**	**Fuel Consumption (MDO)**	**Draught**
July 5, 2018	6	30 NM	3495	11 hrs	6.0 m^3	5.0
July 29, 2018	7	30 NM	3392	10 hrs	6.8 m^3	5.0
Oct 9, 2018	6	30 NM	3481	11 hrs	6.0 m^3	5.0
Jan 18, 2019	10	30 NM	3511	7 hrs	9.1 m^3	5.0
March, 16, 2019	8.2	30 NM	3524	9 hrs	7.7 m^3	5.1

Tables 2 shows all the voyage parameters used to investigate variable ship speed impact on energy efficiency operational indicator.

Table 3: Ships Voyage Report Sheet for Egina-Akpo field

NAME OF VESSEL: Saavedra Tide						
Voyage Period	**Speed (knots)**	**Voyage Distance**	**Cargo Weight**	**Voyage Duration (hrs)**	**Fuel Consumption (MDO)**	**Draught**
May 11, 2017	6	20 NM	4162	8 hrs	4.7 m^3	5.0
June 26, 2017	6	20 NM	4142	8	4.8 m^3	5.0
October 2nd, 2017	6	20 NM	4173	8	4.7 m^3	5.0
October 28, 2017	6	20 NM	4153	8	4.7 m^3	5.0
Nov 19, 2017	6	20 NM	3991	8	4.7m^3	5.0

Tables 3 shows all the voyage parameters used to investigate the impact of constant ship speed on energy efficiency operational indicator. The ship voyage report for both routes take into

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account all voyages completed between June 2017. And November 2019.

III. RESULT AND ANALYSIS

In order to investigate the behaviour of CO_2 emissions on variable speed, and repeated constant speed, analysis was carried out on two different voyage routes. The first investigated the impact of variable speed, while the second investigated repeated constant speed impact.

A. Impact of EEOI on different ship speed

EEOI is a function of CO_2 emission, and distance sailed. And so, the higher the EEOI values, the higher the CO_2 emission, and ultimately increased fuel consumption. On this basis, Fig 2. Illustrates the relationship between speed, and energy efficiency operational indicator (EEOI). It can be seen that the EEOI values increases with the corresponding increase in ship speed for same voyage distance (30NM), and voyage route (Onne-Akpo Field). By utilizing this model, it is possible to estimate the CO_2 emissions during any given voyage.

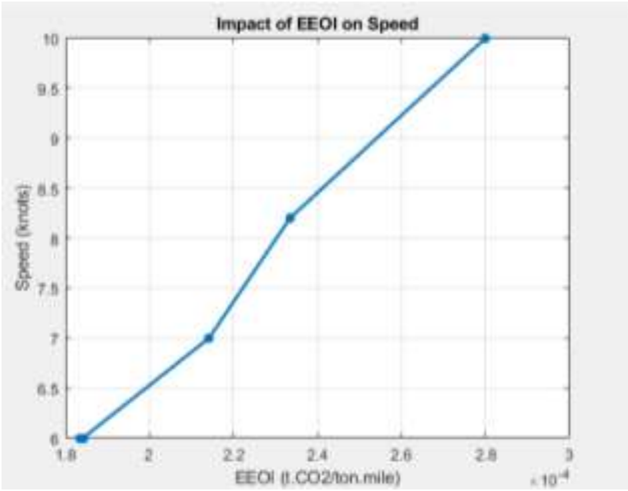

Fig 2: Impact of EEOI on Variable Ship Speed

B. Impact of EEOI on Fuel Consumption

Since this section was modelled by selecting all the voyage operations from Onne-Akpo field at different speeds of the vessel, and also, since speed is a function of fuel consumption, Fig 3. Shows clearly that CO_2 emissions increases as fuel consumption increases. When the fuel consumption was at 6 tons, the vessel recorded EEOI value of about 1.834 x 10^{-4}. When fuel consumption was at 6.8 tons, EEOI value also increased to 2.142 x 10^{-4} t.CO_2/tonne-mile.

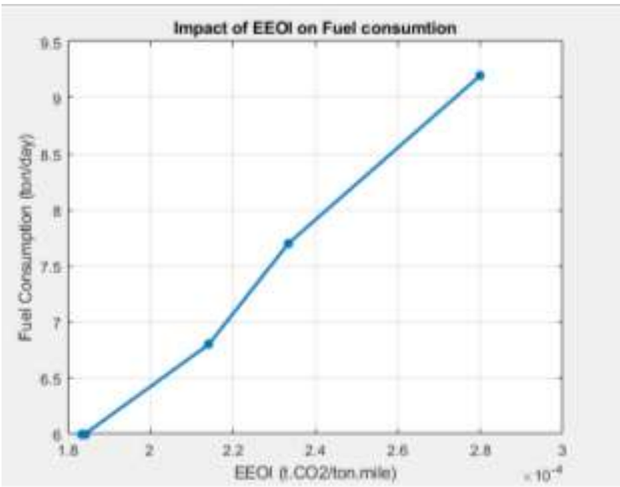

Fig 3: Graph of Correlation Between EEOI and Fuel Oil Consumption

C. Impact of speed on Fuel Oil consumption

The corresponding values of fuel oil consumption with changing speeds is illustrated in figure 4. When the vessel was operating at 6 knots, the fuel consumption was at 6 tons. When the vessel was operating at 7 knots in the same voyage route (Onne-Akpo field), the amount of fuel oil consumed increased to 6.8 tons with a significance difference of 10%-11% as can be observed from figure 4 below. This positive correlation illustrates that ship-owners, and ship operators can save a lot of fuel when operating at optimum speed.

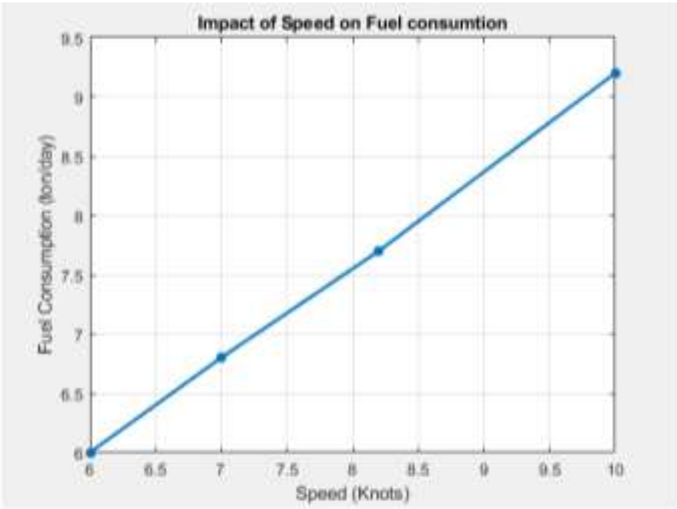

Fig 4: Graph of Correlation Between speed and Fuel Oil Consumption

D. Impact of Speed on voyage Duration

In order to shed more light on the impact of energy efficiency design index on ship operation, it is important to discuss the impact of speed on voyage duration. Figure 5, clearly indicates the arrival time of the vessel at different ship speed in (Onne-Akpo field). At the speed of 6 knots, the vessel arrived in about 11 hours, at 8.2 knots she arrived in about 9 hours. The result shows a negative correlation, meaning increase in ship speed will always reduce the duration of the voyage but, under normal/favourable operating conditions.

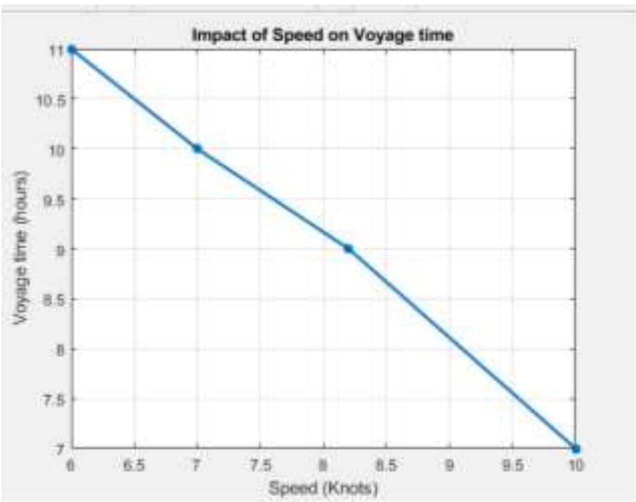

Fig 5: Graph of Correlation Between Speed and Voyage Duration

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E. Comparison Between the EEOI Values at Variable Ship Speed and EEOI Values at Repeated Ship Speed

This section attempts to compare the result of the EEOI values at variable ship speed, and that of constant ship speed of 6 knots to further investigate the impact of energy efficiency design index on ship operation. From Figure 6, the blue line chart indicates the EEOI values for the voyages from Onne to Akpo field, while the red line chart represents the voyage operations in Egina-Akpo field. It can be seen clearly that the EEOI values for the voyages at Onne-Akpo field increased significantly at different ship speeds, while the EEOI values for Egina-Akpo field operations remains at a steady level in all the five voyages as a result of constant ship speed during the operations. The significant increase in the EEOI values as can be seen in the blue line chart due to changing ship speed indicates increase in CO_2 emissions, and fuel consumption at different ship speed, while the red line chart indicates steady emission levels, and steady fuel consumption at repeated constant speed.

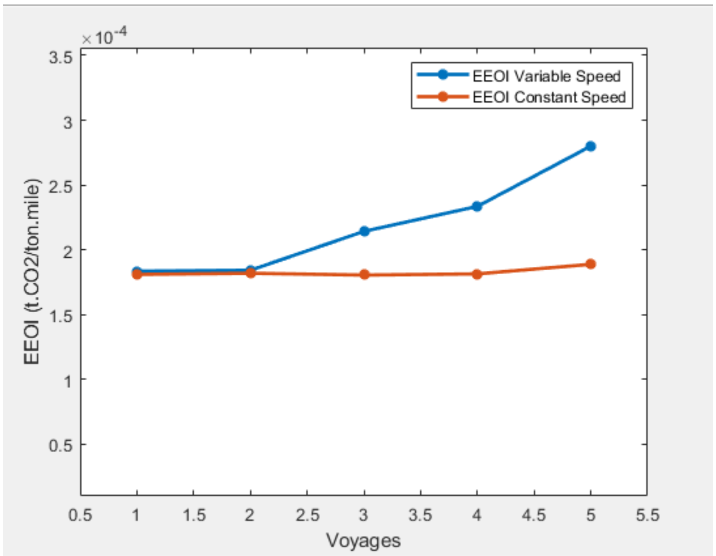

Fig 6: Comparison between EEOI (v speed) and EEOI (repeated constant speed)

IV. CONCLUSION

Ship energy efficiency design index EEDI plays a significant role in the shipping industry where fuel consumption is the biggest concern for all ship owners. Operations of marine machineries also cause the significant emissions of greenhouse gases (GHG) which aggravate ecotoxicology, global warming, and environmental degradation. This research is undertaken to minimise GHG emissions such as CO_2, NOx, SOx, hydrocarbons, etc. which are ecotoxic, hazardous to human life, acidic to marine biology and responsible for rapid decay of social infrastructure and climate change. The research evaluates various ship's EEDI parameters that influence the energy efficiency operational indicator (EEOI) values of ships. It implements canonical formulae proposed by IMO, statistical relations and regression models for its analysis.

The results show a relationship between fuel oil consumption, and ship speed on one hand; and their impact on EEOI on the other hand. The linear relationship between fuel consumption, and carbon emissions was also observed in this research. As indicated, EEOI readily varies with changes in operating parameters (type of fuel, ship speed, sea state of route, deadweight, etc.). Hence, it is inappropriate to use the obtained value as a basis for generic comparison with the EEOI values of other ships. Since the amount of CO_2 emitted from ships is directly related to fuel consumption, the EEOI can also provide useful information on ships performance with regards to fuel efficiency, and the overall cost-efficient operation of the ship.

With bunker prices increasing steadily, it is necessary that ship-operators finds out best practices for efficient ship operation. When the fuel consumption is at 6 tonnes, the vessel records EEOI value of 1.834 x 10^{-4} tonnes CO_2/tonnes-mile. Similarly, with fuel consumption of 6.8 tonnes, EEOI value rises to 2.142 x 10^{-4} tonnes CO_2/tonnes-mile. The potentials for shipping to provide both fuel-efficient, and low-polluting transport however, depends on more widespread use of existing abatement technologies. Furthermore, although the fuel efficiency of shipping is already high, there is still room for improvement, which will be a competitive advantage in a future with expected high fuel prices.

REFERENCES

[1]. Chen, S., Frouws, K. & Van de Voorde, E. (2010). 'Technical changes and impacts on economic performance of dry bulk vessels', Maritime Policy and Management, 37(3), pp. 305-327.

[2]. De Larrucea, J. R (2012). "Energy Efficiency Design Index (EEDI) Marpol Annex VI: Legal Framework and Regulatory problems", Technical University of Catalonia (UPC-Barcelona Tech).

[3]. Deltamarin LTD, (2011). Study on tests and trials of the Energy Efficiency Design Index as developed by the IMO, Applicability and Refinement of the EEDI for Ro-Ro and Ro-Pax Vessels, Report for Project 6543, 2011.

[4]. Devanney, J. (2011). The impact of the energy efficiency design index on very large crude carrier design and CO_2 emissions. Ships O_shore Struct. **2011**, 6, 355–368.

[5]. Huilin, R., Yu, D. &Congbiao, S. (2019). Influence of EEDI (Energy Efficiency Design Index) on Ship–Engine–Propeller Matching.

[6]. ICCT (2011). "The Energy Efficiency Design Index (EEDI) for New Ships", Policy Update 15, October 3-2011.

[7]. IMarEST, Colfax, (2015). Making the green agenda pay, viewed 27 March 2015, ⟨http:// www.imarest.org/all-docman-docu ments/representation/green-agenda/551-making-the-green-agenda-pay/file⟩.

[8]. IMO (2011). Reduction of GHG emissions from ships Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measu res (MEPC62/INF.7). IMO.

[9]. IMO (2011). Sulphur oxides (SOx) – Regulation 14. Available at: http://www.imo.org /OurWork /Environment/PollutionPrevent ion/AirPollution/Pages/Sulphur-oxides-(SOx) Regulation-14.aspx.

[10]. IMO (2012). Guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships (MEPC 63/23 Annex 8 Resolution MEPC.212(63)). IMO.

[11]. IMO (2012). Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP), MEPC 63/4/11.

[12]. IMO (2014). "2014 Guidelines on the method of calculation of the Attained Energy Efficiency Design Index (EEDI) for new ships", MEPC 66/21/Add.1 p: 1.

[13]. IMO, (2015). EEDI database–Review of status of technological development-Note by the Secretariat, Marine Environment Protection Committee, MEPC 68/INF.13, London.

[14]. Kanu, P. J. (2012). Impacts of Energy Efficiency Design Index. Impacts of Energy Efficiency Design Index (A Thesis for the degree of Master of Science in Marine Transport with Management), Delft University of Technology.

[15]. Kesicki. F. & Ekins P. (2012). Marginal abatement cost curves: a call for caution. Climate policy, 12, 219-236.

[16]. MEPC (2014)."Marine Environment Protection committee (MEPC),67th session, 13to17October 2014. "from http://www. imo.org/MediaCentre/Meeting Summaries /MEPC/Pages /MEPCU67thUsessionAspx.

[17]. Rehmatulla, N. & Smith, T. (2015). Barriers to energy efficiency in shipping: a triangulated approach to investigate the principal agent problem in shipping. Energy Policy 84, 44–57.

[18]. Tadeusz, B., Lech, K. &Przemysaw, K. (2012). Energy Efficiency Design Index of Container Vessel – Operational Approach

[19]. UNFCCC, (2015). Adoption of the Paris Agreement, viewed 04 January 2016, (https://unfccc.int/resource/docs/2015/cop21 /eng/l09r01.pdf⟩.

[20]. UNCTAD. (2018). Review of Maritime Transport 2018; United Nations Publication: New York, NY, USA; pp. 23–26.