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POWER REDUCTION CONSIDERATIONS FOR BULK CARRIERS WITH RESPECT TO NOVEL ENERGY EFFICIENCY REGULATIONS

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Summary

After introducing an energy efficiency design index (*EEDI*) in 2011, International Maritime Organization (IMO) pursued their short- and long-term goals to reduce greenhouse gas (GHG) emissions from ships by presenting, among others, an energy efficiency existing ship index (*EEXI*). Contrary to *EEDI* which is used for new ships solely, *EEXI* is addressing an energy efficiency of already built ships and is set to become formally applicable starting from 2023. Existing designs cannot be essentially and rapidly changed to comply the criterion. The only main particular from the preliminary design phase that can be meaningly optimized “post festum” is a required engine power, and thus, the speed. Therefore, the paper explores the effect of *EEXI* policy on a fleet of 153 bulk carriers built between 2000 and 2020 in order to address their near future and prompt design changes, specifically considering the power reduction. For that purpose, an attained and a required *EEXI* are calculated for each ship. The results showed that only 15% of the ships built in 2000-2012 satisfied 2013-2014 IMO criterion. This impacted the design of ships built in 2013-2022, as they complied the same criterion by 88% of share. However, no ship from the whole database satisfied the present day *EEDI* requirement and only one ship fulfilled the contemporary *EEXI* requirement meaning that the current designs are not able to match the emerging criteria to a large extent. In order to meet an energy efficiency criterion, a main engine power reduction and speed are predicted assuming that the engine power and shaft limiter are installed. The investigation showed that *MCR* reduction of the total fleet taken into account had to be reduced by 50% and speed by 15% on average in order for ships to meet current requirements. Moreover, a graphic method is developed for the estimation of *EEXI* by using only deadweight (*DWT*) and maximum continuous rating (*MCR*). The proposed simplified method based on average values could be used on existing bulk carriers with an aim to satisfy novel regulation with application of “easy to use” approach. Additionally, authors discussed other options to reliably evaluate an energy efficiency of existing ships.

Key words: *energy efficiency; EEXI; EEDI; ship design; bulk carriers*

1. Introduction

Following the Paris Agreement on climate change and global emission reduction goals, IMO presented an initial strategy for the decarbonization of ships in 2018, see [1]. It included three levels of ambitions, considering both short- and long-term predictions. In the first one, IMO detailed and reviewed already implemented *EEDI* requirements for ships, which were introduced in 2011 and set in use starting from 2013 [2]. Since 2015, *EEDI* requirements are planned to be strengthened every five years. Before 2015 (i.e., phase 0), a required *EEDI* reference line was the criterion, so that ships built in the period 2013-2014 had to achieve their own attained *EEDI* lower than required *EEDI* reference line. In the phase 1, ships built in 2015-2019 had to satisfy the same *EEDI* reference line, but reduced by 10%. In the phase 2, for the ships which are being built in 2020-2024, the reduction of the *EEDI* reference line criterion is obliged to be 20%; whereas for the ship built after the 2025, the reduction is set to be 30% of the reference line. In the second level of ambition, IMO aim was to reduce CO_2 emissions per transport work, on average for shipping, to 40% until 2030 while trying to reach even 70% until 2050, when compared to the 2008 values. The third level included a desire to achieve peak of GHG emissions more rapidly and to reduce total annual GHG emissions until 2050 by at least 50%, comparing to the 2008. In the meantime, *EEDI* criteria, and consequently the slow steaming approach, already reduced an installed power, lowered shaft speed and increased propeller diameter of new ships, see [3].

Furthermore, in order to address emissions from existing ships, IMO [4] introduced *EEXI* requirements for ships falling under the MARPOL Annex VI, and over 400 GT, such was in case of *EEDI*. Likewise, a calculated (attained) *EEXI* of the ship has to be lower than required *EEXI* reference. *EEXI* requirement will be used from 2023 for existing ships such as bulk carriers, tankers, container ships, etc. Final *EEXI* calculation procedure is adopted at MEPC meeting in 2021 [5], while next IMO review of the criteria is expected to be in 2026. *EEXI* very much corresponds to *EEDI* second and third phase criteria. Although these recent short-term measures with respect to *EEDI* and *EEXI* governed the power reduction of the main engine, the long-term IMO ambitions are expected to potentially propel the use of alternative solutions (alternative fuels, optimization solutions, use of wind, etc.). Furthermore, this could also drive to lower speeds, but not so necessarily or directly, because certain ship types are already navigating at reduced speed and engine power. Therefore, the main challenge currently appears to be the estimation of power and speed to comply to *EEXI* requirements.

A review of the IMO energy efficiency policy from the beginning can be found in [6]. Study [7] presented a comprehensive review of technical changes and fuel consumption trends for bulk carriers built from 1970 until 2006. Particularly, an effect of slow steaming on a bulk carrier fleet is examined in [8]. Paper [9] concluded that bulk carriers built between 2005 and 2014 showed no significant performance improvement. Somewhat the same was noted in [10**,** 11] implying that the implementation of efficiency measures for bulk carriers were almost negligible. Paper [12] identified 2014-2016 as years from which the bulk carriers delivered lower *EEDI* since they were impacted by the IMO policy. Furthermore, energy efficiency improvements for bulk carriers are examined in [13]. More on ship optimization with respect to EEDI, potential emission reduction measures and energy saving device analysis can be found in [14], [15], [16], respectively.

Authors of this paper have been exploring energy efficiency measures effect on ship design in the case of multi-purpose cargo vessels, see [17]. Results showed that most of the present fleet designs could not meet even the first phase of *EEDI* criterion let alone the second and the third phase requirements, except for the ships with lower speeds. Furthermore, the analogous was shown in [18], where *EEXI* calculation is performed on four existing ships type representatives (container ship, bulk carrier and oil tanker).

This paper presents the investigation on how the bulk carrier fleet of 153 ships built in the past 20 years (2000-2020) are relating to the novel energy efficiency policies. Furthermore, while examining the share of ships that could not comply to current *EEXI* criterion, authors studied the effect of meeting such requirements on ship's installed power and speed. Therefore, assuming that the engine power limiter is installed, a reduction of power and speed is predicted for each ship. Also, a graphic method is proposed to estimate *EEXI* of bulk carriers by using just two parameters: *DWT* and *MCR*. Besides, authors discussed a possibility for more reliable evaluation of energy efficiency of existing ships.

2. Database

Most ships are conducted from the RINA's Significant Ships [19] journal and moreover, updated with additional bulk carriers for which the authors had obtained reliable data from the shipyards. Ships having lesser deadweight than 12000 t were eliminated from the database since they have been mostly related to the sea-river navigation. Furthermore, certain ships had additional "booster" engines installed (shaft generators), but those were excluded from analysis in order to achieve more uniform database with respect to power source. Finally, the gathered database used for the analysis consists of 153 bulk carriers built from 2000 until 2020. Particulars have the following ranges, in terms of L_{OA}, *DWT*, *GT*, respectively: 107 m - 362 m, 12588 t - 400000 t and 5686 – 203403. More detailed particulars are presented in Figures 1-5. Authors did not have all the data needed for each ship. Therefore, for instance (and for some ships), a block coefficient is estimated according to displacement and *L*, *B*, *T*.

Figures 1-4 are showing the ships' particulars as a function of deadweight. In Figure 5, as similarly observed in [3], one can note the tendency of increasing the propeller diameter and reducing the shaft speed of ships in years (2010-2012) in which the energy efficiency regulations started to emerge. Shaded areas present the 95% and 94% of the ships from the database in terms of *D* an *n*, respectively.

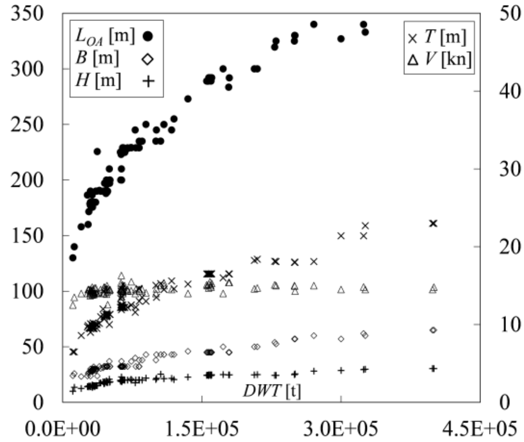

Fig. 1 *L_{OA}, B, H, T, V vs. DWT*

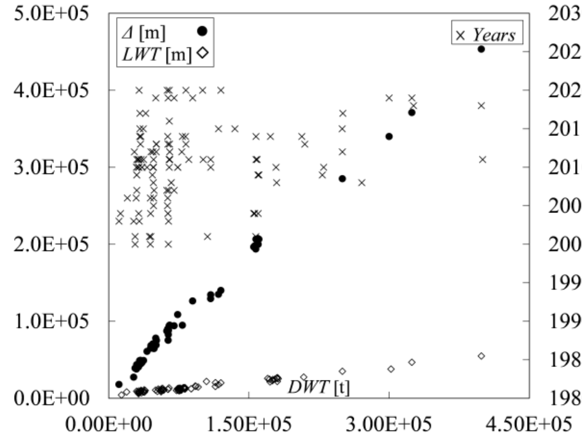

Fig. 2 *Δ, LWT, Years* vs. *DWT*

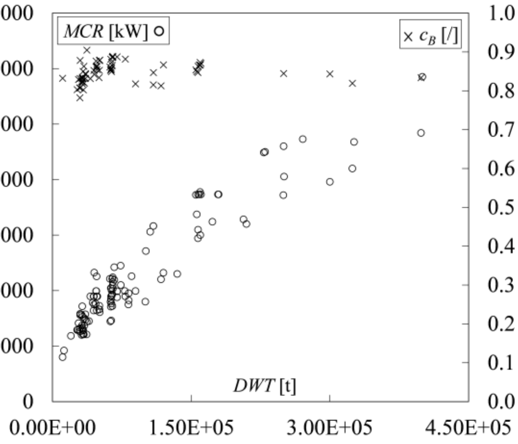

Fig. 3 *MCR*, c_B vs. *DWT*

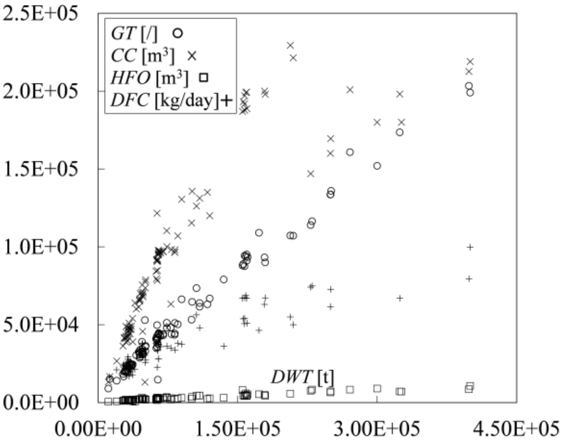

Fig. 4 *GT*, *CC*, *HFO*, *DFC* vs. *DWT*

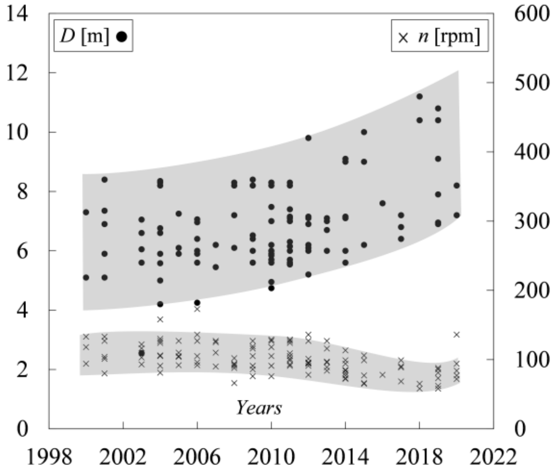

Fig. 5 *D*, *n* vs. *DWT*

3. Methodology

For each ship, an attained *EEXI* and a required *EEXI* are calculated, according to [20] and [21], respectively. This means that an attained *EEXI* should be lower than a required *EEXI*, see equation (1), in order that the ship could be considered as energy efficient. In the following sections, a full procedure for the calculation of EEXI is described.

$$\text{Attained}\, EEXI \leq \text{Required}\, EEXI \tag{1}$$

3.1 Attained *EEXI*

General method to calculate an attained *EEXI* is given in equation (2) and taken from [20].

$$\text{Attained}\, EEXI = \frac{\left[\begin{array}{l} \left(\prod_{j=1}^{n} \cdot f_j\right)\left(\sum_{i=1}^{n_{ME}} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE*}\right) + \\ \left(\left(\prod_{j=1}^{n} \cdot f_j \cdot \sum_{i=1}^{n_{PTI}} P_{PTI(i)} - \sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{AEeff(i)}\right) \cdot C_{FAE} \cdot SFC_{AE}\right) - \\ \left(\sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME**}\right) \end{array}\right]}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot f_W \cdot V_{ref} \cdot f_m} \tag{2}$$

A report from [20] provides detailed explanations for equation (2). Namely, a subscript "*" means that, if part of the normal maximum sea load is provided by shaft generators, SFC_{ME} and C_{FME} may, for that share of the power, be used instead of SFC_{AE} and C_{FAE}. Additionally, subscript "**" requires that, in case of $P_{PTI(i)} > 0$, an average weighted value of ($SFC_{ME} \cdot C_{FME}$) and ($SFC_{AE} \cdot C_{FAE}$) should be used for the calculation of P_{eff}. Note that all 153 ships have one main engine and no shaft generators. Moreover, they have no innovative mechanical energy efficient technologies applied on main nor auxiliary engines. Hence, Table 1 summarizes the assumptions made corresponding to equation (2).

Table 1 Assumptions used for equation (2)

One engine (main)	$\sum_{i=1}^{n_{ME}} P_{ME(i)} = P_{ME(1)}$
No shaft generator	$\sum_{i=1}^{n_{PTI}} P_{PTI(i)} = 0$
No innovative energy efficient technologies on main engine	$\sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{eff(i)} = 0$
No innovative energy efficient technologies on auxiliary engine	$\sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{AEeff(i)} = 0$

Consequently, an equation (2) is being transformed to equation (3).

$$\text{Attained}\, EEXI = \frac{P_{ME} \cdot C_{FME} \cdot SFC_{ME} + P_{AE} \cdot C_{FAE} \cdot SFC_{AE}}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot f_W \cdot V_{ref} \cdot f_m} \tag{3}$$

Engine power (P_{ME}) is defined as 75% of the maximum continuous rating (MCR). Auxiliary engine power (P_{AE}) is calculated according to [22] recommendation, see equation (4), and taking into account that there is no shaft generator.

$$\begin{aligned} P_{AE} &= 0.5 \cdot MCR \; (MCR < 10000\,\text{kW}) \\ P_{AE} &= 0.025 \cdot MCR + 250\,(MCR \geq 10000\,\text{kW}) \end{aligned} \tag{4}$$

Since there is no full list of available data for each ship from the database, authors used a detailed estimation procedure published in [20] to estimate the particulars presented as follows. Accordingly, the following is approximated: $SFC_{ME,app}$ = 190 g/kWh, $SFC_{AE,app}$ = 215 g/kWh, $C_{F,app}$ = 3.114 t CO_2/t·fuel. The subscripts "$_{ME}$" and "$_{AE}$" refer to the main and auxiliary engine, respectively. For the purpose of calculation, it is more reliable to obtain a reference speed (V_{ref}) from speed-power curve, but such is not disclosed to the authors. Nevertheless, V_{ref} is determined from equation (5) from [20]. Furthermore, authors also used the same report for the estimation of $V_{ref,,avg}$ and MCR_{avg}, which is based on ship type and DWT. The same recommendations define a performance margin (m_v) as minimum among 5% of $V_{ref,avg}$ and 1 kn. Additionally, $Capacity$ is defined as DWT for scantling draught, while the correction factors (f_i, f_c, f_l, f_w, f_m) are calculated from the procedure presented in [22].

$$V_{ref,app} = V_{ref,avg} - m_v \left[\frac{P_{ME}}{0.75 MCR_{avg}} \right]^{1/3} \tag{5}$$

Apart from speed-power data, the database does not include sea trial report with *EEDI* calculation, nor draft at design load condition. Both could be useful since they already include parameters needed for the calculation of *EEXI*. Moreover, reference [18] states that ships, if applicable, can use their previously calculated attained *EEDI* instead of attained *EEXI*, if attained *EEDI* is equal or less than attained *EEXI*.

3.2 Required *EEXI*

The required *EEXI* is calculated considering the procedure given in [21] for bulk carriers, see equation (6), with corresponding parameters shown in Table 2.

$$\begin{aligned}&\text{Required}\,EEXI=\left(1-\frac{Y}{100}\right)\cdot\text{Reference line}\\&\text{Reference line}=a\cdot b^{-c}\end{aligned}\tag{6}$$

Table 2 Parameters for the calculation of required *EEXI*

Y (reduction factor)	*a*	*c*	*b*
15 ($DWT \geq 200000$) 20 ($20000 \leq DWT < 200000$) 0-20[1] ($10000 \leq DWT < 20000$)	961.79	0.477	*DWT* ($DWT \leq 279000$) 279000 ($DWT > 279000$)

[1]Regarding the bulk carriers with DWT between 10000-20000 t, the reduction factor *Y* should be linearly interpolated between two values.

4. Results

The ships from the database are assessed with respect to the energy efficiency criteria developed since 2011. The aim was to investigate their energy efficiency level and its influence on power and speed from the start of energy efficiency indices application. Firstly, the database is divided into two categories; the ships built in 2000-2012 and 2013-2020. The first category of ship designs (built in 2000-2012) could be only applied to the IMO resolution [2] issued in 2011 for new ships (became mandatory for the years 2013-2014), since there were no energy efficiency requirements for existing ships at the time. Therefore, an attained *EEXI* calculated from sect. 3.1 is assessed to the phase 0 required *EEDI* [2]. Such required *EEDI* used the same reference line and reduction factors as in the case of required *EEXI*, defined as in equation (6) and Table 2. This comparison could be performed since attained *EEXI* (sect. 3.1) and attained *EEDI* from [2] are supposed as equal and defined according to equation (3), if an equivalent assumption were adopted (see Table 1), as stated by [21]. Such assessment provides a view on how 2000-2012 period designs would relate to the firstly introduced energy efficiency criterion.

The results are plotted in Figure 6 showing that only 15% of ships built in the period 2000-2012 would satisfy phase 0 *EEDI* criterion that were used for 2013-2014. Since there was no need, no energy efficiency measures were considered before the regulations were introduced. However, a share of 88% of the ships built in 2013-2020 satisfied the same criteria. The design change followed the introduction of IMO mandatory requirement and almost exclusively included slow steaming, i.e., power and speed reduction during the navigation. Slow steaming appeared to be only solution that could be promptly applied. Furthermore, *EEDI* requirements tightened over the years following the reduction of the criterion from phase 0 (applied in 2013-2014), to phase 1 (applied in 2015-2019) and phase 2 (started in 2020 until 2024). Phase 2 required *EEDI* is defined by the same reference line criterion from equation (6), as in the case of phase 0 required *EEXI* criterion. However, instead of *Y* from Table 2 used in the phase 0, a new reduction factors are introduced: $Y = 20$ (for ships with DWT equal or above the 20000 t) and $Y = 0 - 20$ (for ships with DWT of 10000 t and above but less than 20000 t). Therefore, the criterion remains the same for lighter ships, but strengthened for ones having DWT over the 200 000 t, see Figure 6. Contrary to the ships built in 2012-2020 that could mostly satisfy the *EEDI* 2013-2014 requirement, no ship is complying with the current *EEDI* reference line. Moreover, only one ship satisfied *EEXI* requirement and is represented by one of largest, an ultra large crude carrier with 398595 t of *DWT*. Thus, in a 7-year period, the standard designs became unacceptable from the energy efficiency point of view. This has been expected to make a huge impact on ship design.

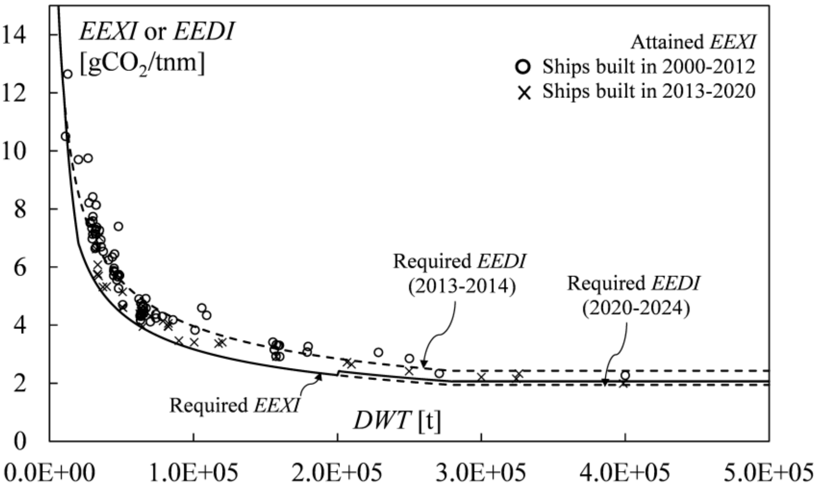

Fig. 6 Energy efficiency indices

Therefore, authors investigated the extent of possible solution in reduction of power/speed of the ships. This could be performed, as per IMO suggestion, by an installation of engine/shaft power limiter (EPL/ShaPoLi) system as most easy to install solution to reduce attained *EEXI*, see more on their application and types in [23]. EPL limits maximum engine power, both mechanically and electronically, while SHaPoLi limits the shaft power.

4.1 Power reduction

According to [23], the installation of EPL/SHaPoLi system requires the power of the main engine (P_{ME}) to be calculated as in equation (7), and limited installed power (MCR_{lim}) as in equation (8).

$$P_{ME} = \min(0.83 \cdot MCR_{\mathrm{lim}}; 0.75 \cdot MCR) \tag{7}$$

$$MCR_{\mathrm{lim}} = EPL_x \cdot MCR \tag{8}$$

MCR_{lim} cannot be calculated analytically, so the iterative approach has been used by varying EPL_x for each ship between 0 and 1, where $EPL_x = 1$ means that an attained *EEXI* is already equal or less than the required *EEXI* and that there is no need for power limitation. The Figure 7 shows the required percentage of EPL for each ship in order to reach *EEXI* requirement, where $EPL_x = 1$ stands for $EPL_x = 100\%$. It seems that new policies have larger impact on lighter ships since they require larger power reduction. *MCR* should be decreased for nearly 50% on average to comply with *EEXI* requirement, indicating that many of the ships should navigate significantly slower from 2023. Larger ships with *DWT* above 200000 t are in a more favourable position in that regard. RMS lines are showing the corresponding tendency in which the newer ships (built in 2013-2020) would need less power reduction than in case of older ones (built in 2000-2012), with a difference in EPL_x change varying from around 10% for lighter to 15% for larger ships. When evaluating the results, it should be considered that the database is uneven with respect to *DWT*, with much larger number of ships with DWT below the 150000 t.

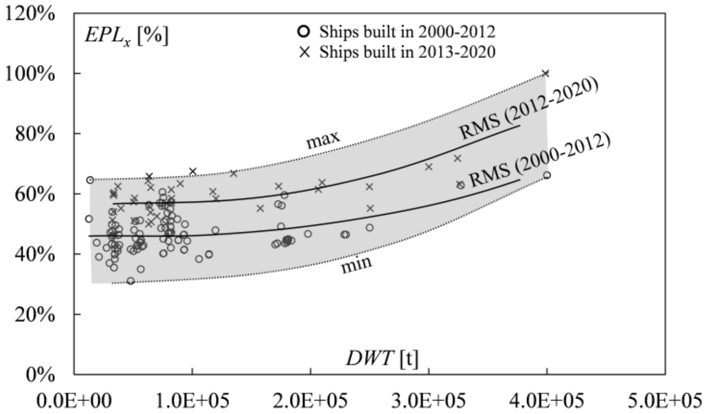

Fig. 7 EPL value for existing ships in database

4.2 Simplification of EEXI evaluation

Evaluation of *EEXI* requires a lot of inputs. Most of them cannot be obtained directly from ship navigation conditions and need to be estimated, which is indeed allowed by IMO resolutions, see sect. 3.1. Although estimations simplify the procedure, they also reduce the calculation time. Thus, in order to allow easy to use energy efficiency check authors proposed simplification of calculation for attained *EEXI* by using only *MCR* and reference speed ($V_{ref, app}$) proposed in [20]. The method is based on the general procedure, assumptions and the equations explained in sect. 3.1 and 3.2. Nonetheless, equation (3) presents the starting point. Following the aforesaid, an assumption is made here regarding the correction factors. Specifically, product of correction factors, which was performed for all 153 ships, is approximated as: $f = f_i \cdot f_c \cdot f_l \cdot f_W \cdot f_m$.

Furthermore, for *MCR* that equals to 10000 kW or above, using equations (3) to (6) and assumptions from Table 1, a new nonlinear equation is derived. Such equation is nonlinear and cannot be solved analytically. However, the solution is obtained in Matlab software by using Newton-Raphson method for finding the roots of the equation. It was based on solving 481 equations for DWT = 1000 – 500 000 t with step of 1000 t. Consequently, $MCR/f^{1.5}$ as a function of *DWT* is calculated for each ship from the database, with ship specific *f* value, and the results are shown in Figure 8 for entire fleet of 153 ships. The boundary line is the required *EEXI* limit from sect. 3.2, which is here recalculated to $MCR/f^{1.5} – DWT$ trend, where $f = 1$ is assumed. Stepped line segments correspond to the change in reduction factor explained previously. This dependency can be used to predict the attained *EEXI* based on ship's *MCR* and *DWT*. As shown, ships below the boundary line satisfy the *EEXI* requirement and the ones over - do not. It can be observed that only one ship from the entire fleet can comply with the requirement. Figure 8 corresponds to Figure 6 (see attained and required *EEXI*) and therefore it is validated accordingly. In both figures, ships are correspondingly distanced from the required reference line. The only ship that was able to comply with the requirement in Figure 6 is the same one to do so in Figure 8.

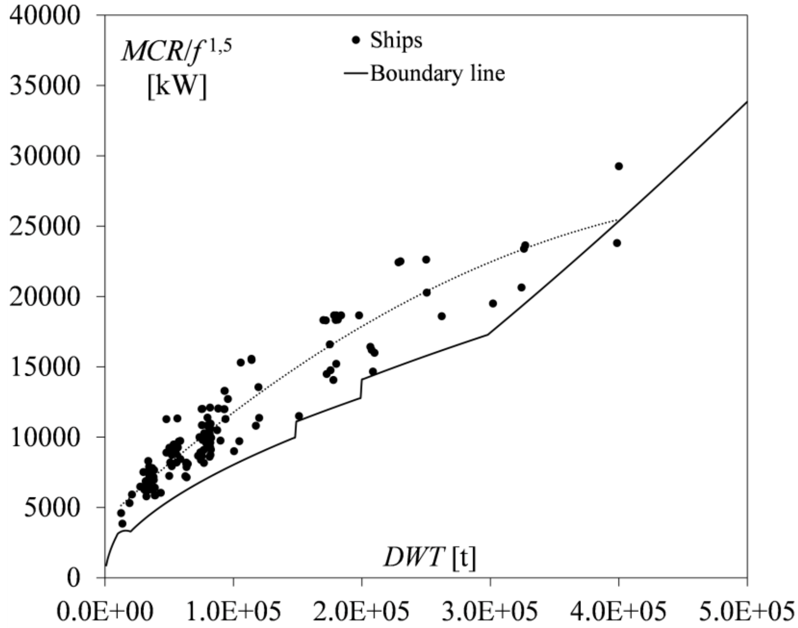

Fig. 8 Simplification of EEXI evaluation

4.3 Simplification of EEXI evaluation with EPL/SHaPoli effect

As in sect. 4.2, authors introduced $V_{ref,app}/f^{\,0.5}$ as a function of *DWT*. The dependency covers the range of *DWT* = 1000 – 400000 t. Contrary to *MCR* and *DWT* inputs form Figure 8, one could estimate ship's *EEXI* performance using $V_{ref,app}$ and MCR. The derivation is performed in the same manner as in sect. 4.2: by using equations and assumptions from sect. 3.1 to produce single nonlinear equation that is solved numerically. The only difference is that $V_{ref,app}$ is used instead of *MCR*. Therefore, Figure 8 is transferred to Figure 9. The derivation of attained *EEXI* data here is performed for each ship without (current status) and with EPL/SHaPoLi, taking into account equations (5) and (7). Similarly, if the speed and *DWT* positions the ship above the reference line, the ship is not energy efficient with respect to *EEXI* criterion. In terms of *EEXI* performance for the fleet, the diagram corresponds to the Figure 8 and 6. Parameter $V_{ref,app,\mathrm{lim}}/f^{\,0.5}$ is also shown in Figure 9 and it presents approximated reference speed after EPL/SHaPoLi installation in order to see the speed reduction. Additionally, EPL/SHaPoLi analysis show that ships would need to reduce their speed according to data below (approximately between 12-18%) to comply with EEXI reference line. Approximated speed reduction is obtained from (RMS/trendlines) prior and after EPL/SHaPoLi installation for a range of *DWT* = 1000 – 400000 t; 18% reduction corresponds for ships less than 200000 *DWT* and 12% speed reduction corresponds for ships larger than 200000 *DWT.*

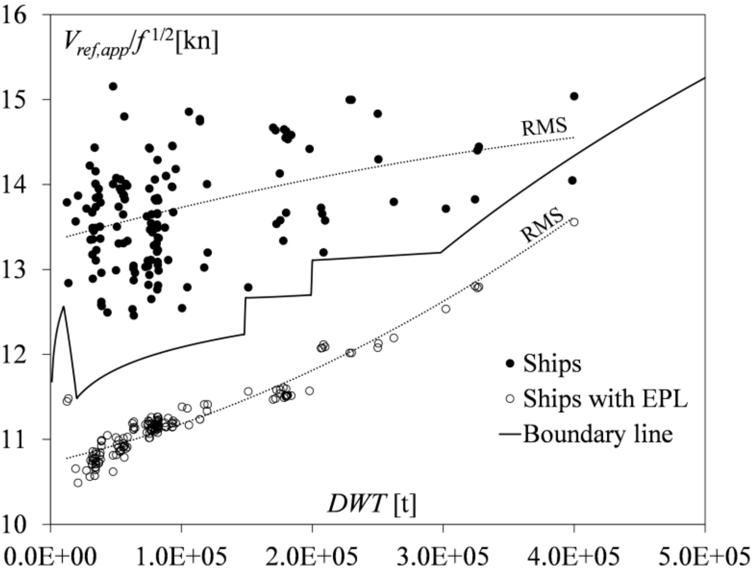

Fig. 9 Simplified EEXI evaluation: before and after the EPL/SHaPoLi

Both reference lines $MCR/f^{1.5}$ and $V_{ref,app}/f^{0.5}$ can be used only for checking the *EEXI* requirements prior the installation of EPL/SHaPoLi. Boundary lines in Figures 8 and 9 are not generic and these lines become ship specific after limiter system integration according to equations (7) and (8) and that is why lower points ($V_{ref,app,\mathrm{lim}}/f^{0.5}$) are not on the boundary line in Figure 9.

4.4 Discussion notes

According to [24], the lowest fuel consumption rate for three engine manufacturers (Wärtsilä, Caterpillar and MAN) is between 70-80% of the engine load. Considering that many ships intended to comply with EEXI requirements have been already sailing in such regime, the actual speed reduction after EPL/SHaPoLi installation should be less than previously mentioned by 12-18%, when ships sail under fully loaded main engine. Regarding the aforementioned sailing regime, the paper shows that the actual speed reduction could be 10-14% for small and 3-7% for large ships according to Figure 9, depending on whether 70% or 80% of engine load is used. Therefore, the speed obtained by sea trials instead of IMO approximated reference speed could be more suitable for *EEXI* calculation because real reference speed can be larger than suggested approximated speed in [20]. In most cases, the existing sea margin could be lost after EPL/SHaPoLi installation, but this wouldn't affect the operation of the ship. Nevertheless, both methods presented here (sect. 4.2 and 4.3), based on *MCR* or $V_{ref,app}$, provide direct solution on the amount on power and speed reduction needed for the *EEXI* compliance. Such could not be obtained in original *EEXI* procedure, see sect. 3.1 and 3.2.

5. Conclusion

Energy efficiency policies that have been developing over the years appeared to had impact on bulk carriers built in the past 20 years, according to the database of 153 ships presented here. The study here showed that:

- 15% of the bulk carriers built in 2000-2012 complied the 2013-2014 *EEDI* IMO criterion, and 88% of the bulk carriers built in 2013-2020 complied the 2013-2014 *EEDI* IMO criterion,

- no bulk carrier complied the present day *EEDI* criterion and only one bulk carrier complied the present day *EEXI* criterion (largest by DWT).

Therefore, current designs cannot satisfy the contemporary energy efficiency requirements. In the interregnum in which the industry was waiting for the alternative fuel solutions, power (speed) reduction has been governing *EEXI* compliance for most of the ships. For presented fleet, roughly, *MCR* reduction is estimated to be 50%, followed by the 15% of speed reduction. *EEXI* analysis is performed using statistical estimations, especially regarding speed, which is allowed and proposed by respective IMO resolutions. Nonetheless, *EEXI* prediction should not deviate significantly. However, in order to address energy efficiency evaluation in more reliable manner, an actual speed-power curve should be obtained, not by estimations, but by sea trials as most accurate method. Furthermore, a graphical method is derived to evaluate *EEXI* performance of bulk carriers. Contrary to the original procedure with numerous particulars needed for the assessment, the method is based solely on *MCR* and *DWT* or $V_{ref,app}$ and *DWT* for easy check. The method instantly provides an amount of power or speed reduction for the criterion fulfilment. Therefore, due "user-friendly" approach, this method can be used onboard to allow energy efficient navigation during each loading condition change, so EPL/ShaPoLi would not be needed.

Nomenclature

B – breadth [m];

Capacity – equal to deadweight [t];

c_B – block coefficient [/];

CC – cargo capacity [m^3];

$C_{F,app}$ – approximated conversion factor between fuel consumption and CO_2 emission for main engine and auxiliary engine [tCO_2 / t·Fuel];

C_{FAE} – conversion factor between fuel consumption and CO_2 emission for auxiliary engine [tCO_2 / t·Fuel];

C_{FME} – conversion factor between fuel consumption and CO_2 emission for main engine [tCO_2/ t·Fuel];

D – propeller diameter [m];

DFC – daily fuel consumption [kg/day];

DO – diesel oil capacity [m^3];

DWT – deadweight mass [t];

$EEDI$ – energy efficiency design index [gCO_2/tnm];

$EEXI$ – energy efficiency existing ship index [gCO_2/tnm];

EPL_x – reduction coefficient for *MCR* [/].

f – total correction factor [/];

fc – cubic capacity correction factor [/];

f_{eff} – innovative mechanical energy efficient technology factor [/];

f_i – capacity correction factor [/];

f_l – factor for general cargo ships equipped with cranes and other cargo-related gear [/];

f_m – factor for ice-classed ships having IA Super and IA [/];

f_w – factor for speed reduction at sea [/];

GT – gross tonnage [/];
H – height [m];
HFO – heavy fuel oil capacity [m^3];
L – length between perpendiculars [m];
L_{OA} – length over all [m];
LWT – lightweight mass [t];
MCR – maximum continuous rating [kW];
MCR_{avg} – average maximum continuous rating [kW];
MCR_{lim} – maximum continuous rating after installing EPL [kW];
m_v – performance margin [kn];
n – shaft speed [rpm];
n_{ME} – number of main engines [/];
n_{PTI} – number of shaft engines [/];
P_{AE} – power of auxiliary engine [kW];
$P_{AE,eff}$ – innovative mechanical energy efficient technology for auxiliary engine [kW];
P_{eff} – innovative mechanical energy efficient technology for main engine [kW];
P_{ME} – power of main engine [kW];
P_{PTI} – power of shaft engine [kW];
SFC_{AE} – specific fuel oil consumption for auxiliary engine [g/kWh];
$SFC_{AE,app}$ – approximated specific fuel oil consumption for auxiliary engine [g/kWh];
SFC_{ME} – specific fuel oil consumption for main engine [g/kWh];
$SFC_{ME,app}$ – approximated specific fuel oil consumption for main engine [g/kWh];
T – draught [m];
V – design speed [kn];
V_{ref} – reference speed [kn];
$V_{ref,app}$ – approximated reference speed [kn];
$V_{ref,app,lim}$ – approximated limited reference speed [kn];
$V_{ref,avg}$ – average reference speed [kn];
Y – reduction factor [/];
Δ – displacement [t];
η_{DWT} - deadweight ratio [/].

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