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Investigation of the New Type City Lines Passenger Ship in terms of Energy Efficiency

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Abstract. Energy efficiency in ships is a practice that purposes to reduce CO_2 gas emissions and reduce worldwide environmental pollution by using less fossil oils, less greenhouse gas releases. This practice requires technical measures to be taken on new ships and new systems (machines, propellers, etc.) in order to make new ships more energy efficient. In this study, one of the newly built passenger ship that used in transportation in the Istanbul Strait was analyzed in terms of energy efficiency performance, the energy efficiency design index (EEDI) was calculated and the applicable measures to reduce CO_2 exhaust gas emissions were presented. In the calculations, it was investigated whether the ship meets the energy efficiency criteria as planned. As a result of the analysis, it was seen that the ship is an energy efficient ship and complies with IMO standards. Measures were specified to increase the ship's energy efficiency.

Keywords: EEDI, MARPOL, Emissions, Vessel, IMO

1. Introduction

The International Maritime Organization (IMO) has made a new directive in order to avert airborne pollution caused by vessel flue gases and has implemented the Annex VI in the MARPOL 73/78 convention in line with the targets set in the UN Framework Convention on Climate Change and the Kyoto Protocol. There are many new measures taken by IMO within the scope of Annex VI [1]. The measures cover all commercial vessels navigating in international waters with a tonnage of 400 GT and above. Among these measures, it is intended that novel ships and existing ships will be energy efficient and emit less emissions. Actions put into practice for vessels to be energy efficient;

1. The Energy Efficiency Design Index (EEDI) aims the ships to use less fossil fuel, to reduce CO_2 emissions with less greenhouse gas emissions, and reduce global air pollution. The EEDI application covers all new ships to be built [2]. This practice is meant that novel vessels will be more energy efficient and this practice mandates practical actions and the installation of novel systems (propellers, engines, etc.).

2. The Ship Energy Efficiency Management Plan (SEEMP) envisages to take operational actions to ensure that all ships are cost-effectively energy efficient. SEEMP has been included in Marpol Annex VI (Chapter 4 by IMO directive MEPC.1/Circ.681) [3]. SEEMP covers all commercial vessels over 400 GT currently underway. The application was made compulsory as of 01 January 2013.

With the EEDI and SEEMP applications, IMO aims to reduce the emissions of the merchant fleet until 2050. The emission reduction and the new emission levels to be achieved is shown in Figure 1. With the energy efficiency studies to be carried out according to Figure 1, it is aimed to reduce the CO_2

emissions of the maritime fleet by EEDI and SEEMP applications in 2050 by half compared to the emissions in 2010 [4].

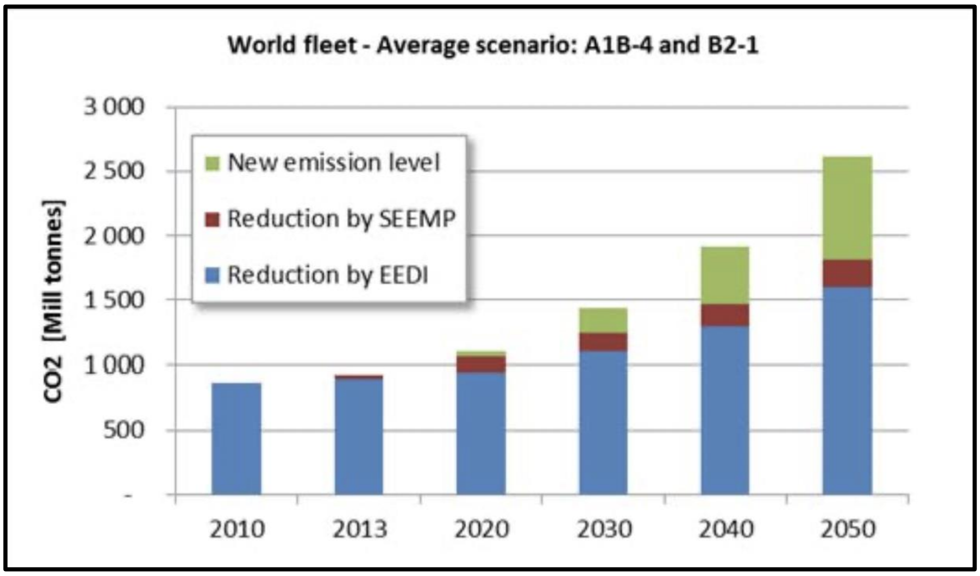

Figure 1. The emission reduction and the new emission levels [4]

EEDI applications on the basis of ship types were examined in scientific studies and the results were explained in detail in literature studies. In the studies, it was emphasized that the implementation of EEDI applications on ships was very crucial in reducing greenhouse gases. When surveyed the major studies in the literature review, Borkowski et al. [5] studied the EEDI calculation method for container ships and a new calculation method was developed to be used in the calculation. The energy efficiency of the bulk carrier named M/V Jules Garnier was inspected by Tien [6] according to the EEDI index and applicable measures were presented to increase the energy efficiency of the ship. 351 cargo ships used in transportation in Bangladesh were analyzed in terms of energy efficiency by Zakaria and Rahman [7]. Since it is impossible to modify existing ships and their limited carrying capacity, applicable EEDI measures were developed for existing ships. For new ships, new applicable EEDI measures specific to the ship types in the region were proposed. The methods that arise the energy efficiency of the ships and accordingly lessen the CO_2 emissions were examined by Talay et al. [8]. The methods that can be applied to the ships in the design, operations, coordination of the navigation plans and maintenance were presented in the study. Kaya and Erginer [9] examined the practices and approaches of the shipyard companies to ensure energy efficiency and reduce greenhouse gas emissions on ships. Tokuslu [10-12] studied one of the container ships and the sea-buses in Turkey. Some concrete suggestions were offered to expand the energy efficiency of ships during terms. Based on the ship-engine-propeller matching principle, the application of EEDI applications on the WinGD 5X52 marine diesel engine was investigated by Ren et al. [13].

These researches focus on the energy efficiency of current and novel vessels and offer applicable measures to make ships more energy efficient. The level of implementation of the IMO regulations regarding the lessening of greenhouse gas emissions from vessels by the maritime sector has been revealed in the studies. In this study, the energy efficiency of the MARPOL EEDI applications put into practice as of January 01, 2013, a newly built passenger ship that used in transportation, was analyzed, EEDI was calculated, and the applicable measures to decrease CO_2 exhaust gas emissions were presented. Measures were specified to upsurge the energy efficiency of the ship. This study is one of the few studies conducted in Turkey in this field on the energy efficiency of ships, and it is considered that it will contribute to the literature in this respect.

2. Methodology

The EEDI application by IMO has been planned by directing the vessel types larger than 400 GT and the highest fuel consumption of the commercial sea fleet. With this goal, it is expected to make 72% of the maritime commercial fleet environmentally friendly [14].

When examined the EEDI implementation schedule, the energy efficiency of the ships built between 2000 and 2010 was taken as a basis and it was calculated how the ships could be more energy efficient in this direction. EEDI executions have been started as of January 01, 2013 and plans were completed each 5 years. The execution schedule to be implemented over the years according to the EEDI stages is shown in Figure 2. It was foreseen that energy efficiency will be implemented at 10% at the first stage and it was meant to increase to 30% by 2030. It was intended to upsurge this ratio to 50% by 2050.

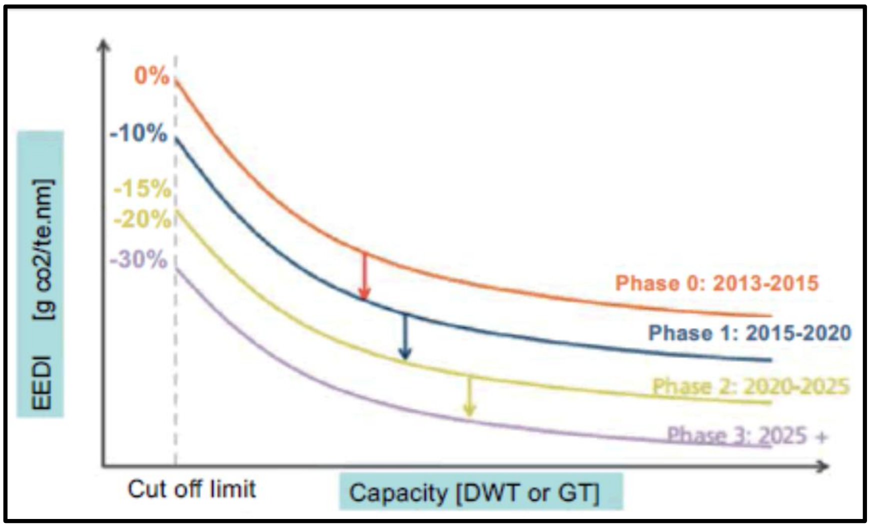

Figure 2. EEDI execution schedule [4]

2.1. Calculation method

EEDI predicts lowest energy usage and minimum CO_2 emission for unit load carried per ton/mile in dissimilar vessel categories and models. EEDI is a method in which the vessel's energy efficacy is calculated with the help of formulas, in which the design features of the ship are included in the process from the project of the ship in a way that will lessen the CO_2 emissions that the ship emits per ton/mile [2]. The EEDI equation (1);

$$EEDI = \frac{\mathrm{P} * \mathrm{SFC} * \mathrm{Cf}}{\mathrm{DWT} * \mathrm{Vref}} \qquad (1)[2]$$

P : 75% of the power of engines (main and auxiliary) in kW
SFC : Amount of oil scorched by engines (main and auxiliary) in kW
C_f : Emission rate of oil (presented in Table 1)
DWT : Capacity of ship (in tons)
V_{ref} : Ship speed (in knots)

Table 1. Carbon content and C_f values of different types of fuel [16]

Type of fuel	Reference	Carbon Content	C_f (t-CO_2/t-Fuel)
Diesel / Gas Oil	ISO 8217 Grades DMX through DMB	0.8744	3.206
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.8594	3.151
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.8493	3.114
Liquefied Petroleum Gas (LPG)	Propane	0.8182	3.000
	Butane	0.8264	3.030
Liquefied Natural Gas (LNG)		0.7500	2.750
Methanol		0.3750	1.375
Ethanol		0.5217	1.913

With the EEDI calculation method, how energy efficient a ship will be can be calculated. Different constants and coefficients were used in the EEDI equation. IMO MEPC Resolution 245 (66) presents the detailed explanations of carbon content and C_f values of different types of fuel [15]. The attained EEDI is found with calculation method and the attained EEDI must not exceed the reference (line) EEDI, if this reference (line) EEDI is less than the attained EEDI, the vessel cannot be measured energy efficient. Reference (line) EEDI (2) can be calculated with the equation 2 given below.

$$\text{Reference (line) EEDI} = a \times b^{-c} \quad (2)$$

For the reference (line) EEDI calculation, the parameters a, b and c determined according to the vessel types are shown in Table 2. Baseline values are derived from ship information in the database of Lloyd's Register Fair Play [2, 4, 16]. There are exemplary reference lines for vessel types created from database of the Lloyd's Register Fair Play, and according to these standards, reference lines are created and calculations are made according to the vessel type to be used in the analysis. It is possible to create a common reference line for other vessel types other than Table 2 (by using information such as tonnage, engine power, speed, aspect ratio, etc.).

Table 2. Parameters (a, b and c) for the reference line EEDI [2]

Vessel types specified in directive	a	b	c
Bulk Dry	961.79	DWT	0.477
Liquefied Gas Carriers	1120	DWT	0.456
Tanker	1218.8	DWT	0.488
Container	186.52	DWT	0.201
General Cargo	107.48	DWT	0.216
Roro Cargo	1405.15	DWT	0.498
Roro Passenger	752.16	DWT	0.381
LNG Carrier	2253.7	DWT	0.474
Cruise passenger ship having non-conventional propulsion	170.84	GRT	0.214

2.2. Ship particulars

In 2015, it is planned by the Istanbul Metropolitan Municipality to add 10 new passenger ships, which will pollute the environment less, are energy efficient and are suitable for disabled access, to the Istanbul city lines fleet, replacing the old ships. One of the first ships, the S/H Durusu passenger ship (IMO No: 9764922) (Figure 3) was produced in Yalova and entered the inventory in 2015. The reason for examining the ship within the scope of this study is to evaluate the level of MARPOL EEDI implementations put into practice as of 01 January 2013 on a new ship built in Turkey and to examine whether the newly built ship is energy efficient or not.

Parameter	Value
Flag	Turkey
IMO No	9764922
Lenght	41,2 m
Breadth	10 m
Draught	2,5 m
Deadweight (DWT)	294,08 tons
Main engine type	Scania DI13 070M
Main engine power (MCR)	736 Kw
Service speed	13 knots
Passenger capacity	700

Figure 3. S/H Durusu

3. Results and discussion

This study analyzed whether the ship is energy efficient or not with EEDI calculations. The reference EEDI and the attained EEDI using equations (1) and (2) were calculated. The attained EEDI value must be smaller than the reference EEDI value for the vessel to be measured energy efficient. First of all, the reference line of the ship helps to find the reference EEDI value. The reference line (using information such as tonnage, engine power, speed, aspect ratio, etc.) of the existing city line ships fleet was calculated by Erat [17], and it was seen in this study that the same reference line is still up-to-date (Figure 4). The reference EEDI is :

Reference line value (reference EEDI) = $a \times b^{-c}$ = 226,37 x $294{,}08^{-0{,}172}$ = 85,161 (gCO_2/ton.mile)

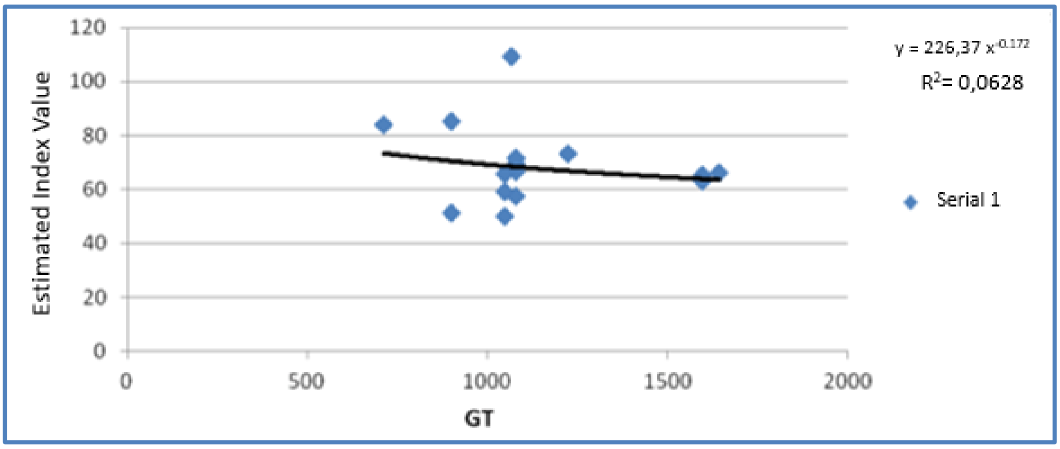

Figure 4. Reference line of the city line ships fleet [17]

For passenger ships in the calculation, 75% of the tonnage (GT) is used to calculate the power of main engine (P(ME)) [4, 18]. The main engine power (P(ME)) for the studied ship was calculated as 552 kW. Auxiliary engine power is also included in the calculation according to the power of main engine. If the power of main engine is ≥ 10.000 kW, the power of auxiliary engine is estimated as (P(AE) = (0.025 x power of main engine) + 250), if the main engine power is < 10.000 kW, the power of auxiliary engine (P(AE) = (0.05 x main engine power)) [4, 18]. According to this calculation, since the main engine power of the ship is less than 10.000 kW, the auxiliary engine power (P(AE)) is calculated as 36.8 kW. In order to save fuel, the fuel used by the ship is diesel fuel (MDO) and the emission factor was found as C_f 3.206 from Table 1 [14]. The diurnal consumption of diesel fuel by the main engine (SFC(ME)) is 165 kW, and the diurnal consumption of diesel fuel by the auxiliary engine (SFC(AE)) is 220 kW [14]. The attained EEDI was estimated according to equation 1.

$$\text{Attained EEDI} = \frac{(P\ (ME) * SFC\ (ME) * Cf(ME)) + (P(AE) * SFC\ (AE) * Cf(AE))}{DWT * Vref} = \frac{(552 * 165 * 3{,}206) + (36{,}8 * 220 * 3{,}206)}{294{,}08 * 13} = 83{,}169\ (gCO_2/\text{ton.mile})$$ [4, 18, 19]

According to the calculation, the reference EEDI (85,161) is greater than the attained EEDI (83,169), the vessel appears as an energy efficient ship and the ship emits less CO_2 than other ships of its type. There is no need to implement EEDI measures at this stage, as the ship's attained EEDI value does not exceed the reference EEDI value. However, with the EEDI reduction measures that can be applied, it will be possible to ensure that the ship is more energy efficient and emits less CO_2. One of the EEDI reduction measures is the speed reduction measure that the ship can easily apply. Table 3 shows the different calculation times for different main engine loads and the speed reduction rates that the ship can apply according to these calculation times. During the cruise with the studied ship, the power of main engine and the vessel actual speed were measured at each machine load ratio, and it was seen that the values were in agreement with the values specified in the design of the ship. The attained EEDI (gCO_2/ton-mile) values according to the speed reduction were shown in Figure 5. Since the tonnage of the ship and the fuel used did not change in the calculation, the tonnage and C_f value were used as in the first calculation. It has been observed that the attained EEDI values of the studied ship have decreased even more with the speed reduction made, and the ship has become more energy efficient. In the study conducted by Mersin [20] and Tokuslu [12], it was revealed that fuel consumption decreased significantly by reducing the ship speed to 5, 6, 7, 8 knots.

Table 3. New EEDI calculation times based on host load rates

Main Engine Load Ratio	Calculation Times	Main Engine Power (kW)	Tonnage	Cf	Speed
%100	CT-1	736	294,08	3,206	13
%90	CT-2	663	294,08	3,206	12
%80	CT-3	589	294,08	3,206	11
%70	CT-4	515	294,08	3,206	10
%60	CT-5	442	294,08	3,206	9

It can be seen from Figure 5 that the speed reduction measure provides better performance in terms of EEDI, the vessel turns out to be more energy efficient, and as a result, the vessel releases less CO_2 emissions. It was considered that it would be much more beneficial in this respect if the vessel cruised at 10 or 11 nautical miles, which is also an economical speed.

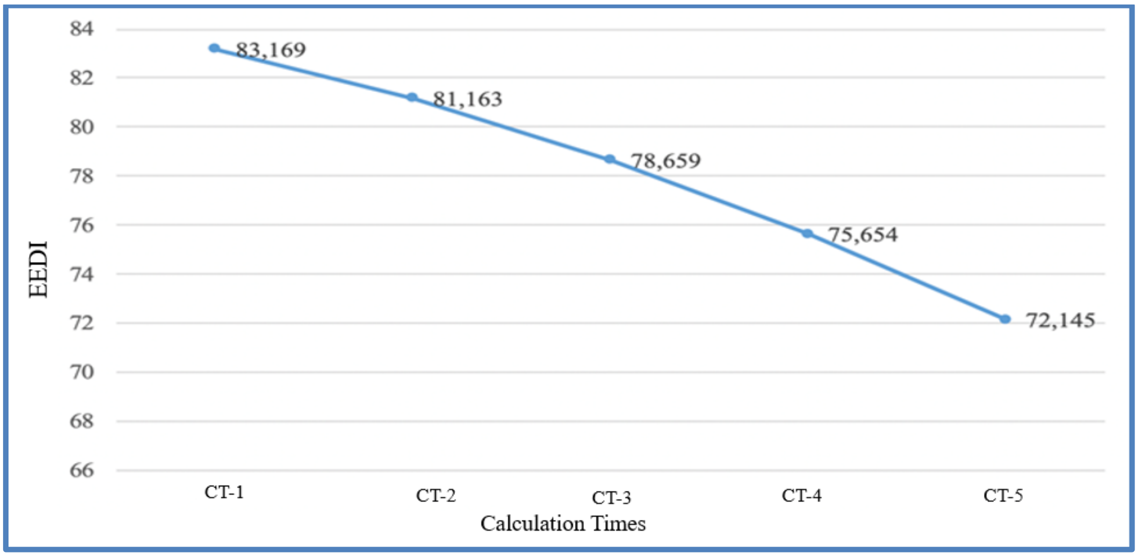

Figure 5. New EEDI values according to speed reduction measure

4. Conclusion

In this study, the energy efficiency performance of a newly built passenger ship used in transportation in the Istanbul Strait was examined. In the calculations, it has been analyzed that the ship is an energy efficient ship that complies with the EEDI criteria as it was aimed in the construction. The ship was built in 2015. It has been observed that the studied ship is within the scope of MARPOL EEDI's regulation, which is mandatory for newly built ships as of 01 January 2013. It is considered that SEEMP procedures can be executed for the ship to be energy efficient in the following periods, and these measures will increase the current EEDI performance of the ship. For better performance, the ship should implement the measures stated below;

a. The speed reduction measure provided better performance in terms of EEDI, the vessel turned out to be more energy efficient, and the vessel released less CO_2 emissions. It was considered that it would be much more beneficial in this respect if the vessel cruised at 10 or 11 nautical miles, which is also an economical speed.
b. The ship's propeller and hull purifying should be done intermittently,
c. The ship should navigate on routes that avoid rough seas and currents which contribute to energy efficiency.

These actions will keep the attained EEDI to less than 83,169 gCO_2/tonne and maintain the vessel's energy efficiency. It has been demonstrated by the study that it is important to consider the existing EEDI measures in the construction phase for the newly built passenger ships in the future. This study is very important in terms of determining whether the EEDI criteria dictated by IMO are applied in one of the ships built after 2013. After that, by measuring the energy efficiency of other types of ships, it will be possible to have more detailed information about the current energy efficiency status of the Turkish merchant fleet.

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