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Energy Efficiency of a Passenger Ship in Turkey

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Abstract. The International Maritime Organization (IMO) introduced a new measure in 2011 with a set of technical innovation and performance standards to increase the energy efficiency of new ships at the design stage and aim to reduce CO_2 emissions. This new measure is called Energy Efficiency Design Index (EEDI) and this became a fast key instrument for the ships to be energy efficient. In this paper, one of the passenger ships in the Istanbul Strait was investigated and its emissions were estimated. The Energy Efficiency Design Index (EEDI) of the ship was calculated. EEDI formula equations based on the study of passenger ships have been compared with the IMO other ship equations and some useful proposals have been presented to reduce the harmful effects of CO_2 exhaust gas emission.

Keywords: EEDI, Ship, Energy, Efficiency, IMO

1. Introduction

International shipping carries about 90% of world trade and is crucial to the functioning of the world economy [1]. The world's population and economy are expected to continue to grow and maritime transportation will need to respond to the demand for its services. When compared modes of transport according to CO_2 emissions, the maritime sector is the greenest and cheapest one. International maritime shipping emits 3% of the world's CO_2 emissions and also distributes NO_X, SO_X, CO, HC, VOC, and particulate matter (PM) emissions as well [2]. The International Maritime Organization (IMO) introduced a new measure in 2011 with a set of technical innovation and performance standards to increase the energy efficiency of new ships at the design stage. This new measure is called Energy Efficiency Design Index (EEDI) and this became a fast key instrument for the ships to be energy efficient [3]. The EEDI is an energy-efficient method that aims to reduce CO_2 emissions and global environmental pollution by using fewer fossil fuels and less greenhouse gas emissions. EEDI is an implementation for all new ships larger than 400 GT. With this implementation, it is aimed that the new ships will be more energy-efficient, and it dictates technical measures and installing new systems (engines, propellers, etc.) for newly designed ships. EEDI foresees minimum energy use and CO_2 emission for unit load per ton/mile in different ship types and models in the process from the design stage [4]. The smaller the ship's EEDI value, the more energy-efficient the ship is and emits less CO_2 emissions. The EEDI didn`t intend to be used as a performance display of the energy efficiency of the present maritime trade fleet. Ships energy efficient measures have been largely studied and many viable solutions have been found and presented in the literature. The literature studies show that these measures all are applicable. A recent study by Ancic et al. [5] concluded that the EEDI by the IMO does not effectively assess a realistic improvement of measures for increasing the ship operating energy efficiency as they can be quite effective in the considered operating point for the EEDI and they proposed a realistic definition of the EEDI, which is based on several representative vessel operating points. They investigated a case of bulk carriers with the proposed approach and the results were discussed to reveal its advantages against the currently used approach. Bøckmann and Steen [6] calculated the Energy Efficiency Design Index (EEDI) and EEDIweather of a 120 m long general cargo vessel. They found that the attained EEDI of the ship 22% lower than the ship's actual CO2 emissions per transport work. In Beaufort 6 wind and waves, EEDIweather was also estimated using three different calculation methods for the added resistance due to waves. Tien [7] assessed and calculated the EEDI Index in the Field of Ship Energy Efficiency for a bulk carrier with ship name M/V Jules Garnier and presented measures to improve ship energy efficiency. Zakaria and Rahman [8] analyzed the inland cargo vessels of Bangladesh which have been based on 351 existing vessels. They developed the EEDI for seagoing vessels due to the limitation of carrying capacity and installed main engine power. They proposed some applicable measures to be implemented for the new ships.

Overall, all these studies focused on the energy efficiency of the existing and new ships and show us the importance of necessary researches to implement the IMO`s regulations regarding the reduction of GHG emissions from ships. Therefore, this study investigated one of the passenger/ro-ro cargo ships in the Istanbul Strait and its emissions were estimated. The Energy Efficiency Design Index (EEDI) of the ship was calculated and some useful proposals have been presented to reduce the harmful effects of CO_2 exhaust gas emission.

2. Methodology

The EEDI implementation by IMO has been organized by targeting the following types of ships, which have the largest and most fuel consumption of the maritime fleet. With this goal, it is aimed to make 72% of the merchant fleet energy efficient. Ships with diesel, electric, steam, and hybrid propulsion systems are currently out of this implementation. Ship types to which EEDI will be applied;

a. Oil tankers,
b. Bulk carriers,
c. Gas carriers,
d. General cargo,
e. Container ships,
f. Refrigerated cargo,
g. Combination carriers,
h. Roro cargo ship,
i. Roro passenger ship,
j. Cruise passenger ship [9].

As of January 01, 2013, EEDI implementations have been started and energy efficiency plans have been made every 5 years depending on the technologies that will develop in this field. The EEDI implementation schedule is shown in Figure 1. Energy efficiency is foreseen as 10% in the first phase and it is aimed to increase it to 30% by 2030. This ratio is expected to increase to 50% by 2050.

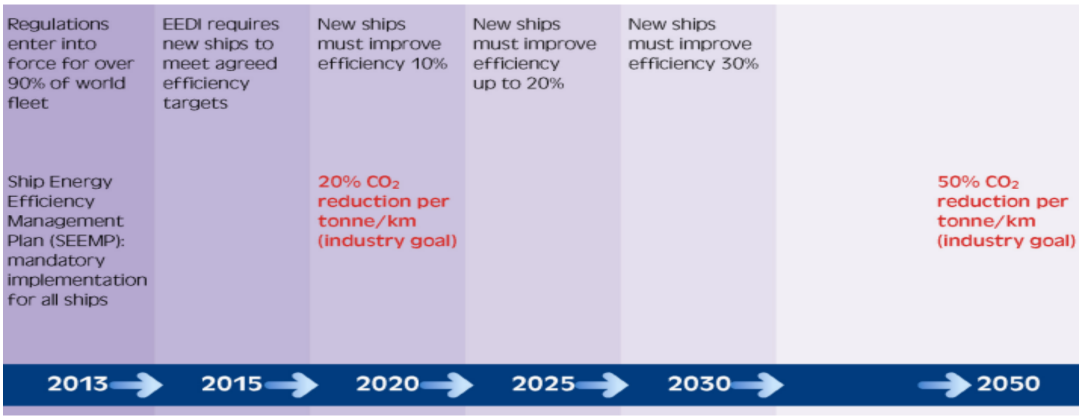


Figure 1. EEDI implementation schedule

2.1. Calculation method

EEDI calculation module was included in Marpol Annex VI with the directive MEPC.1 / Circ.681 at MEPC meeting held by IMO in 2011 and it has been put into effect as of January 01, 2013. The EEDI formula (1) consists of the following equation;

$$EEDI = \frac{CO_2\ \text{Emission}}{\text{Transportwork}} \qquad EEDI = \frac{P * SFC * Cf}{DWT * Vref} \tag{1}$$

(1)[4]

P : 75% of the power of the main and auxiliary engine in kW
SFC : Amount of fuel burned by the main and auxiliary engine in kW (specific fuel consumption)
Cf : Emission rate of fuel used by the ship (presented in Table 1)
DWT : Ship's tonnage (capacity) (in tons)
Vref : Design speed of the ship (in knots)

Table 1. Carbon content and C_F values of different types of fuel [10]

Type of fuel	Reference	Carbon Content	C_F ($t\text{-}CO_2/t\text{-}Fuel$)
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

There are different constants and coefficients in the EEDI formula. Their detailed explanations are available at IMO MEPC Resolution 245 (66) [10]. When the EEDI is calculated for a ship, the attained EEDI is found. The attained EEDI must be less than the reference EEDI or reference line, if the attained

EEDI exceeds this reference EEDI or reference line, the ship is not considered energy efficient. Reference EEDI line values (2) are calculated with the following formula;

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

Reference line value (a, b and c) parameters are presented in Table 2. The reference line values are obtained from the vessel database of Lloyd's Register Fair play. Figure 2 shows us sample reference lines for ship types as per Lloyd's Register Fair play database [4].

Table 2. Reference line value (a, b and c) parameters (the reference EEDI)[4]

Ship type defined in regulation	a	b	c
Bulk carrier	961.79	DWT	0.477
Gas tanker	1120	DWT	0.456
Tanker	1218.8	DWT	0.488
Container ship	186.52	DWT	0.200
General cargo ship	107.48	DWT	0.216
Refrigerated cargo carrier	227.01	DWT	0.244
Combination carrier	1219	DWT	0.488
Roro cargo ship	1405.15	DWT	0.5
Roro passenger ship	752.16	DWT	0.38
LNG carrier	2253.7	DWT	0.47
Cruise passenger ship having non-conventional propulsion	170.84	GRT	0.21

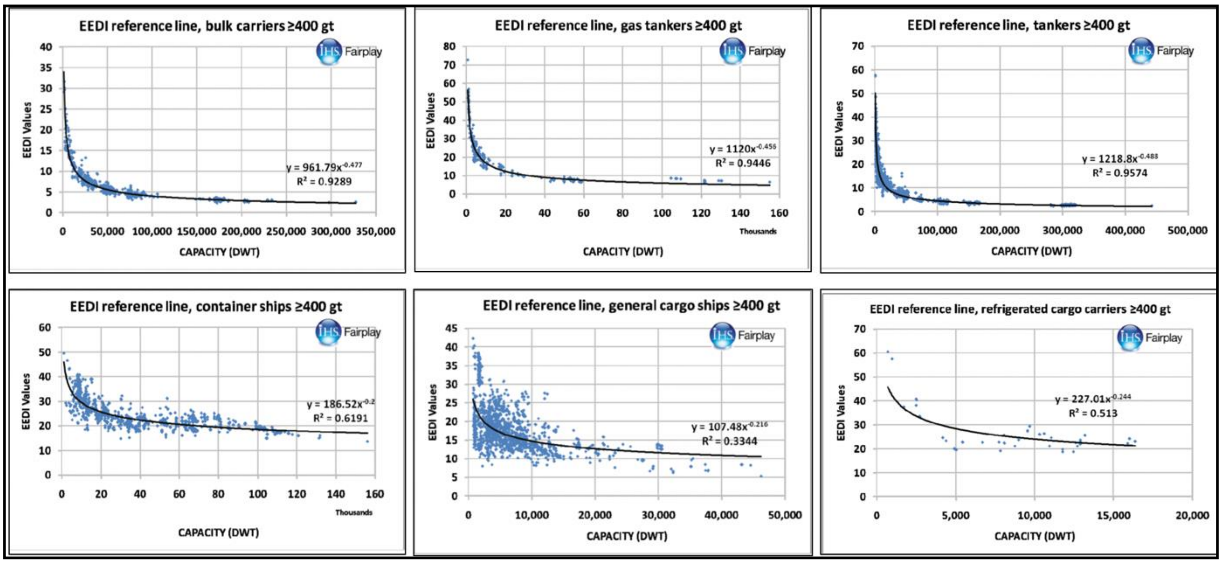


Figure 2. Sample reference lines for ship types developed by the IMO [11]

2.2. Ship particulars

The passenger/ro-ro cargo ship, MF SADABAT, (MMSI: 271002615) is studied in this paper. The ship was built in 2008 in Turkey, navigates in the Istanbul Strait region and ship particulars are presented in Figure 3.

Parameter	Value
Flag	Turkey
IMO No	9415521
Lenght	74 m
Breadth	18 m
Draught	4,2 m
Deadweight (DWT)	1315 tons
Main engine type	Mitsubishi
Main engine power (MCR)	3044 kW
Service speed	12 knots
Vehicle capacity	80
Passenger capacity	596
Navigation lines	Sirkeci-harem, eskihisar-topcular

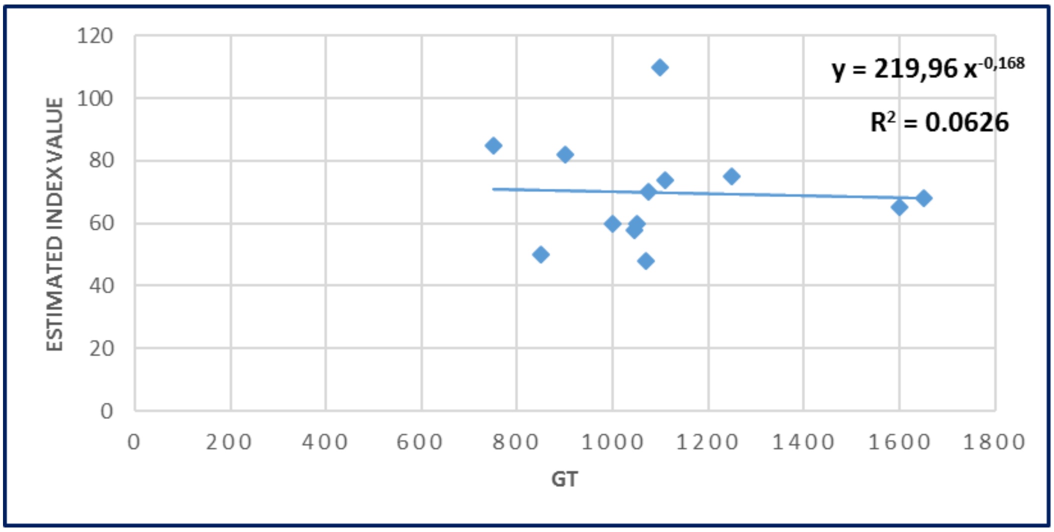
Figure 3. MF SADABAT

3. Results and discussion

Based on the obtained data, the reference EEDI and the attained EEDI of the ship was calculated using equation 1 and 2. The reference line value for the ship is presented in Table 3. The studied ship is a passenger/ro-ro cargo ship and according to its particulars;

Reference line value (reference EEDI) = $a \times b^{-c} = 219{,}96 \times 1315^{-0{,}168} = 65{,}821$ (gCO_2/ton.mile)

Table 3. Reference line value for the MF SADABAT



The attained EEDI must be smaller than the required EEDI (the attained EEDI ≤ the required EEDI). For the passenger/ro-ro cargo ships, 75% of the deadweight (DWT) is used as capacity for calculation of P_{ME} (MEPC 66/21; IMO, 2012). For the studied ship P_{ME} is found 2283 kW. While the main engine power (MCR) is below the 10.000 kW, P_{AE} can be calculated as $P_{AE} = 0{,}05 \times MCR$ and P_{AE} is found 152,2 kW. The ship is using heavy fuel oil (HFO) and its` emission factor C_F is 3.114 from Table 1. Fuel consumption burned by the main engine of heavy fuel oil (HFO) is 190 kW and by the auxiliary engine of heavy fuel oil (HFO) is 215 kW. Calculation of the attained EEDI and required EEDI is;

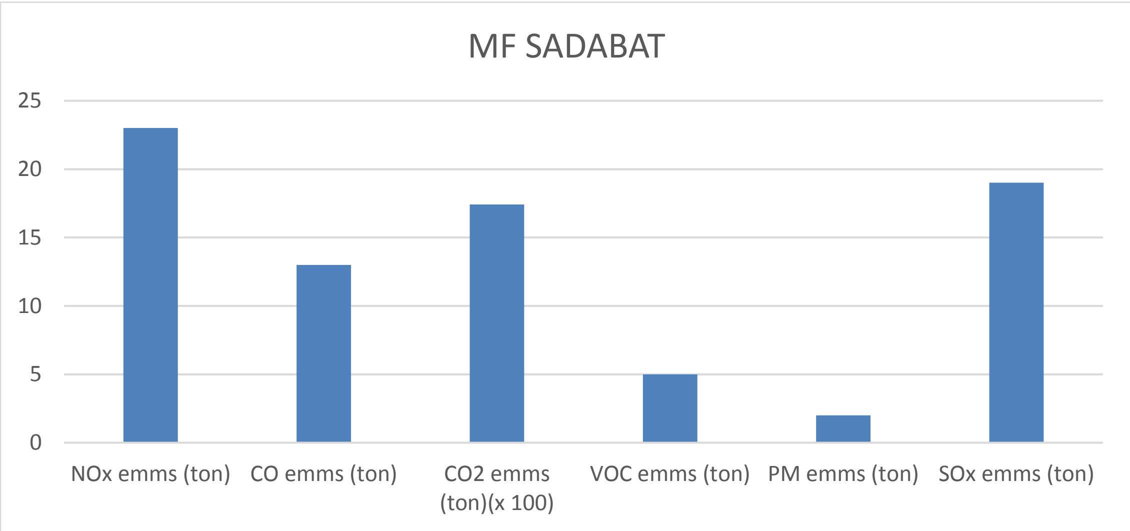
$$EEDI_{attained} = \frac{(P\ (ME) * SFC\ (ME) * Cf(ME)) + (P(AE) * SFC\ (AE) * Cf(AE))}{DWT * Vref} = \frac{(2283 * 190 * 3{,}114) + (152{,}2 * 215 * 3{,}114)}{1315 * 12}$$

= 92,057 (gCO_2/ton.mile)[12, 13, 14]

$EEDI_{required}$ = (1-reduction factor/100) x reference EEDI= (1-5/100) x 65,821 = 62,530

Since the calculated attained EEDI is larger than the reference EEDI, this ship can not be considered as an energy-efficient ship. This vessel exceeds its EEDI value and needs the optimization of the hull form. After implementing EEDI reduction measures, the attained EEDI will be less than the reference line (EEDI) and the ship can be considered as an energy-efficient ship. When we calculated the annual CO_2 emission of the ship (Table 4), we reach that this ship emits 1.741 ton CO_2 yearly. This calculation also gives us an opinion that the target ship is not efficient.

Table 4. The annual exhaust gas emissions of the MF SADABAT



4. Conclusion

In this study, a passenger/ro-ro cargo ship was investigated in terms of EEDI performance and we reached the result that the ship has a poor EEDI performance. However, this ship was built in 2008 and not under the mandatory regulation of MARPOL EEDI but, Ship Energy Efficiency Management Plan (SEEMP) covers all ships so that SEEMP measures can be enforced to become energy efficient. It is very difficult to improve the bad performance of EEDI for the existing ships in the Istanbul Strait region but some EEDI/SEEMP reduction measures can be implemented for better performance, and these measures will improve energy efficiency in the short, medium and long term, measures can be stated such as;

- instead of heavy fuel oil, alternative fuels such as LNG, LPG, gas oil can be used (3-4% reduction),
- hull optimization should be revised for less resistance and be improved advanced underwater hull coatings and monitoring (4-5% reduction),
- speed reduction gives better performance in terms of EEDI (10-15% reduction)
- hull and propeller cleaning should be done periodically (5-10% reduction),
- main and auxiliary engines` exhaust gas waste heat recovery can be done and be implemented conversion to electric power (15-20% reduction),
- while navigating, weather routing such as avoiding rough seas and head currents can be efficient for voyage efficiency (4-6% reduction).

All these measures will help to reduce the attained EEDI (92,057 (gCO_2/ton.mile)) which will become under the reference EEDI (65,821 (gCO_2/ton.mile)). For the future, ship designers or shipyard should consider implementing EEDI requirements for the new ships.

5. Acknowledgments

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