



International Journal of Environment and Geoinformatics (IJEGEO) is an international, multidisciplinary, peer reviewed, open access journal.

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Analyzing the Energy Efficiency Design Index (EEDI) Performance of a Container Ship

Aydin Tokuşlu

Turkish Naval Forces, Ankara, Turkey

E-mail: aydintokuslu78@gmail.com

Received 13 March 2020

Accepted 17 April 2020

How to cite: Tokuslu, A. (2020). Analyzing the Energy Efficiency Design Index (EEDI) Performance of a Container Ship. *International Journal of Environment and Geoinformatics (IJECEO)*, 7(2): 114-000. DOI: 10.30897/ijegeo

Abstract

The International Maritime Organization (IMO) has adopted a new regulation to prevent air pollution from ship emissions which concentrated on reducing green gas emissions from shipping for existing ships, and energy efficiency measures for the new ship. This new regulation imposes a measure which is called Energy Efficiency Design Index (EEDI). This new measure aims to reduce CO₂ 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. In this paper, one of the container ships of the Turkish maritime trade fleet was analysed in terms of energy efficiency performance. The ship's energy efficiency was found as an energy-efficient. Some practical proposals have been presented to improve ship's energy efficiency in the short, medium and long term. This study is the first one which focused on one of the container ship energy efficiency.

Keywords: IMO, Ships, Energy Efficiency, EEDI, SEEMP

Introduction

In line with the targets set out in the UN Climate Change Framework Convention and the Kyoto Protocol, the International Maritime Organization (IMO) has adopted a new regulation to prevent air pollution from ship emissions and has implemented Annex VI in the MARPOL 73/78 convention. These new regulations concentrated on reducing green gas emissions from shipping for existing ships, and energy efficiency measures for new ships (Tokuşlu, 2019). According to UNCTAD 2013 report, bulk carriers, tankers, containers, general cargo ships and gas carriers are the main CO₂ emission polluters and emits the majority of the total CO₂ emissions of the international shipping (Figure 1). These ship types correspond roughly to the ship classification as defined in MEPC 2011.

A large number of existing studies in the broader literature have examined these ships emissions and their port emissions such as; (Buhaug et al., 2009; Endresen et al. 2003; Eyring et al., 2009; Corbett et al., 2007; Cohen et al., 2005; Cofala et al., 2007; Wang et al., 2008; Deniz and Kılıç, 2009; EEA, 2013; Viana et al., 2014; Bayirhan et al., 2019; Mersin, 2020) and these studies have emphasized that ship-borne air emissions have harmful impacts on human health and environment and concrete measures should be taken to reduce its` effects. Although there are many studies in ship exhaust gas emissions, the research in the energy efficiency of ships remains limited. The International Maritime Organization (IMO) adopted 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 measure aims to reduce CO₂ 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 new measure, the new ships will be more energy efficient with its hull optimization, engines, propellers, etc. EEDI enforces minimum energy use and CO₂ emission for unit load per ton/mile in different ship types and models in the process from the design stage (IMO, 2011). The smaller the ship's EEDI value, the more energy-efficient the ship is and emits less CO₂ emissions. A series of recent studies have indicated that ships energy-efficient measures all are applicable and beneficial for reducing CO₂ emissions.

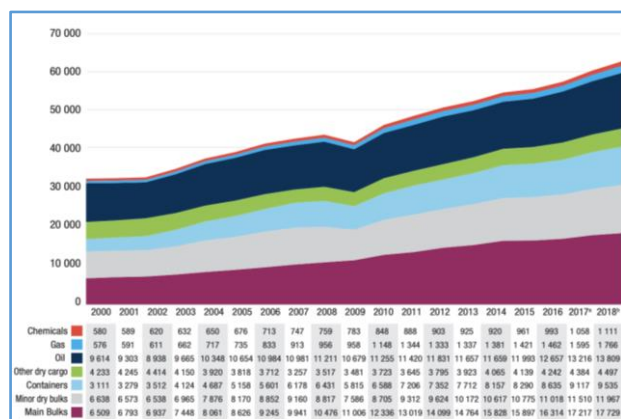


Figure 1. Main CO₂ polluters of international shipping (UNCTAD, 2018).

The literature review shows that EEDI calculation for ships is very important to analyze ships' CO₂ emissions and understand their energy efficiency regarding their impacts on the environment. Ancic and Šestan (2015) estimated the CO₂ emission from bulk carriers based on the current reduction factor change policy. Other policies and some innovative approaches were also discussed and the CO₂ emission in every scenario was estimated. Jack (2011) studied the impact of the energy efficiency design index (EEDI) on very large crude carriers' (VLCCs) CO₂ emissions. They found that over a market cycle, imposition of EEDI would result in a slight increase in VLCC CO₂ emissions, relative to no regulation at all. They concluded that a \$50 per ton CO₂ bunker tax would reduce VLCC CO₂ emissions by more than 6% over a market cycle, and it would do so without forcing the world to devote 30% more resources to a greatly expanded, under-powered, overdriven VLCC fleet. Attah and Bucknall (2015) analyzed future powering options for LNG carriers when considering the Energy Efficiency Design Index (EEDI) and investigated the impacts of this upcoming EEDI regulation, due to be enforced from September 2015, would have on the design of future LNGCs. They found that the current EEDI reference baseline was insufficient to stimulate improvements in the design of future LNGCs because the current Dual Fuel Diesel Electric (DFDE) propulsion proposed to be installed on the majority of future LNGCs orders already achieves EEDI values that are compliant with the EEDI baseline. They also proposed methods to include methane slip emissions into the current EEDI calculations. Longva et al. (2010) presented a new approach where a required index level (IR) was determined through a cost-effectiveness assessment of the available reduction measures. They analyzed the new panamax bulk carrier ship with using eleven emission reduction measures. They concluded that the costs imposed by new requirements could be justified on the basis of the achievable emission reductions and cross-sector potential for achieving a global reduction target. Tien (2015) calculated the EEDI Index for the bulk carrier with ship name M/V Jules Garnier in the Field of Ship Energy Efficiency and presented measures to improve ship energy efficiency. They offered some reducing measures to be implemented. Zakaria and Rahman (2016) evaluated EEDI for inland vessels in Bangladesh. They assessed 526 cargo ships, 247 passenger ships, 70 oil tankers, and 36 ferries in terms of CO₂ emission. The effect of EEDI concerning vessel draft, type of fuel, block coefficient, specific fuel consumption (SFC) and power has been investigated and some viable recommendations have been proposed to reduce the detrimental effects of CO₂ emission by optimizing hull shape of some existing vessels. Overall, all these studies focused on the energy efficiency of the existing and new ships and showed the application of the EEDI implementations under the approved amendments to MARPOL Annex 6.

The Turkish maritime trade fleet ranks 20th in the world and consists of 1260 ships above 300 tonnes such as general cargo, bulk carriers, container ships, oil and gas tankers, passenger ships, service vessels, tugs, fishing

ship, and yachts. Turkish container transport ranks 15th in the world container fleet with its 57 ship (UNCTAD, 2018) and transportation capacity of Turkey's container carryings by seaway was 4.4 million TEU in 2009; in 2018 it enhanced 9.9 million TEU, at the same period imports cargoes boosted to 4.2 million TEU from 2.1 million TEU and the exports cargoes enlarged to 4.1 million TEU when compared with 2.1 million TEU in 2009 (TCS, 2019). Container transportation has an important place in the Turkish trade fleet and its capacity is increasing every day. Examining the energy efficiency of container ships is important to see if MARPOL EEDI implementations are applied. Until now, the energy efficiency of the container ships in the Turkish maritime trade fleet has not been examined. In order to close the gap in this area and to examine the status of container ships, container ship was preferred in this analysis. In this study, one of the container ships has been examined since the necessary data for analysis is provided easily. Energy efficiency of the ship was calculated according to IMO regulations and some useful proposals have been presented.

Materials and Methods

The EEDI implementation covers the designated types of ships, which have the largest and most fuel consumption of the shipping and aims to make 72% of the merchant fleet energy efficient. Ships with diesel, electric, steam, and hybrid propulsion systems are not included in 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 (ICCT, 2007).

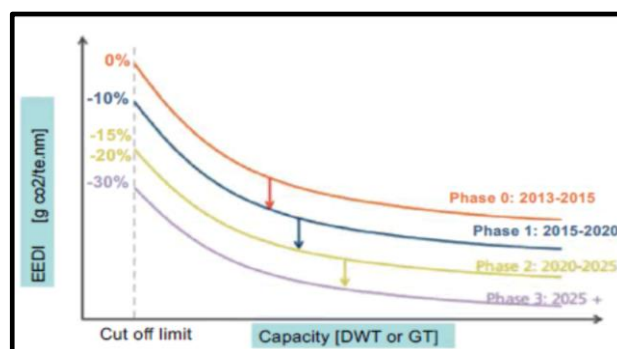


Figure 2. EEDI phases and cut off limits (IMO, 2010)

EEDI implementation tools came into force as of January 01, 2013, and energy efficiency plans have been made every 5 years depending on the new technical and operational solutions for the new ships. The EEDI phases and cut-off-limits is shown in Figure 2. Energy efficiency in the first phase is aimed at 10% and it is

planned to raise it to 30% by 2030. This proportion is anticipated to increase to 50% by 2050.

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) (IMO, 2011) consists of the following equation;

$$EEDI = \frac{P * SFC * Cf}{DWT * Vref} \quad (Eq.1)$$

- P : 70% of the power of the engine (main and auxiliary) in kW
- SFC : Amount of fuel burned by the engines in kW (specific fuel consumption)
- Cf : Emission rate of fuel used by the ship (presented in Table 1)
- DWT : Ship's capacity (in tons)
- Vref : speed of the ship (in knots)

Table 1. Carbon content and C_F values of different types of fuel (MEPC 245 (66), 2014)

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
Liquefied Natural Gas (LNG)	Butane	0.8264	3.030
Methanol		0.3750	1.375
Ethanol		0.5217	1.913

The detailed explanations of the EEDI formula are presented are at IMO MEPC Resolution 245 (66) which consists of different constants and coefficients. When we calculated the EEDI according to this equation (1) for the target ship, the attained EEDI can be found. The reference EEDI must be bigger than the attained EEDI, if the reference EEDI doesn't exceed the attained EEDI, the ship is considered energy efficient. we can calculate the reference EEDI (2) with the formula stated below;

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

Reference line value (a, b and c) parameters are presented in Table 2. The reference line values are provided from the vessel database of Lloyd's Register Fair play. Sample reference lines for ship types are shown in Figure 3 which was created from Lloyd's

Register Fair play database (IMO, 2011). Table 3 presents us with EEDI reduction factors and cut off limits through implementation phases. EEDI reduction factors and cut off limits will help us to calculate the required EEDI based on the year of the ship built. The required EEDI must be bigger than the attained EEDI (the attained EEDI ≤ the required EEDI).

Table 2. Reference line value (a, b and c) parameters (the reference EEDI) (IMO, 2011)

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	174.22	DWT	0.201
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	0.498
Roro passenger ship	752.16	DWT	0.381
LNG carrier	2253.7	DWT	0.474
Cruise passenger ship having non-conventional propulsion	170.84	GRT	0.214

Table 3. EEDI reduction factors and cut off limits through implementation phases (MEPC, 203 (62), 2011)

Ship Type	Size	Phase 0	Phase 1	Phase 2	Phase 3
		1 Jan 2013- 31 Dec 2014	1 Jan 2015 – 31 Dec 2019	1 Jan 2020 – 31 Dec 2024	1 Jan 2025 and onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 DWT and above	n/a	0-10'	0-20'	0-30'
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000-10,000DWT	n/a	0-10'	0-20'	0-30'
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10'	0-20'	0-30'
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0-10'	0-20'	0-30'
General Cargo ships	15,000 DWT and above	0	10	15	30
	3,000-15,000DWT	n/a	0-10'	0-15'	0-30'
Refrigerated cargo carrier	5,000 DWT and above	0	10	15	30
	3,000-5,000 DWT	n/a	0-10'	0-15'	0-30'
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000-20,000DWT	n/a	0-10'	0-20'	0-30'
LNG carrier***	10,000 DWT and above	n/a	10''	20	30
Ro-Ro cargo ship (vehicle carrier)***	10,000 DWT and above	n/a	5''	15	30
Ro-Ro cargo ship***	2,000 DWT and above	n/a	5''	20	30
	1,000-2,000 DWT	n/a	0-5', ''	0-20'	0-30'
Ro-Ro passenger ship***	1000 DWT and above	n/a	5''	20	30
	250-1,000 DWT	n/a	0-5', ''	0-20'	0-30'
Cruise passenger ship*** having non-conventional propulsion	85,000 GT and above	n/a	5''	20	30
	25,000-85,000 GT	n/a	0-5', ''	0-20'	0-30'

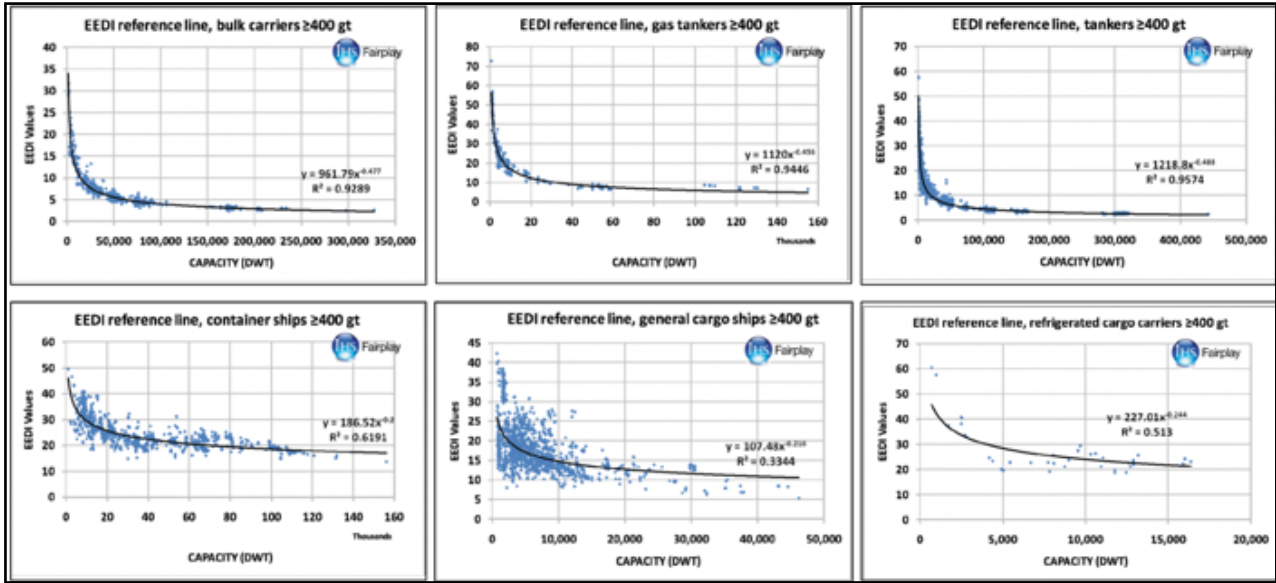


Figure 3. Sample reference lines for ship types (MEPC 62/6/4, 2011)

2.2. Ship particulars

The vessel studied in this present work is the container ship M/V Leyla Kalkavan (9126924)(Figure 4) which was built in 1997 with hull number 109 in Turkey and is sailing under the flag of Turkey. This ship is an average ship in Turkish container fleet and it was chosen because the necessary data for analysis is provided easily. Ship particulars for the study are;

- Length: 136,8 m
- Breadth: 22,7 m
- Draught: 7,7 m
- Deadweight (DWT) : 12.205 tons (1155 TEU)
- Tonnage Gross: 10384 tons
- Tonnage Net: 5070 tons
- Main engine type: Mitsubishi (2-stroke)
- Main engine power (MCR): 10.092 kW
- Service speed: 16 knots



Figure 4. M/V Leyla Kalkavan

Results

The reference EEDI and the attained EEDI of the ship was calculated using equation 1 and 2 with the data we obtained. The attained EEDI must be less than the reference EEDI for the ship to be considered energy efficient. According to ship particulars, the reference EEDI can be calculated as;

$$\text{The reference EEDI} = a \times b^{-c} = 174,22 \times 12205^{-0,201} = 26,285 \text{ (gCO}_2\text{/ton.mile)}$$

The attained EEDI must be smaller than the required EEDI (the attained EEDI \leq the required EEDI). For container ships, 70% of the deadweight (DWT) is used as the capacity for calculation of P_{ME} (MEPC 66/21; IMO, 2012). For the target ship, P_{ME} is found 7064 kW. While the main engine power (MCR) is above the 10.000 kW, P_{AE} can be calculated as $P_{AE} = (0,025 \times \text{MCR}) + 250$ and P_{AE} is found 502,3 kW. The ship is using heavy fuel oil (HFO) and its` emission factor C_F is 3.114. 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}=

$$\frac{(P_{ME}) * SFC_{ME} * C_f(ME) + (P_{AE}) * SFC_{AE} * C_f(AE))}{DWT * V_{ref}} =$$

$$\frac{(7064 * 190 * 3,114) + (502,3 * 215 * 3,114)}{12205 * 16} = 23,125$$

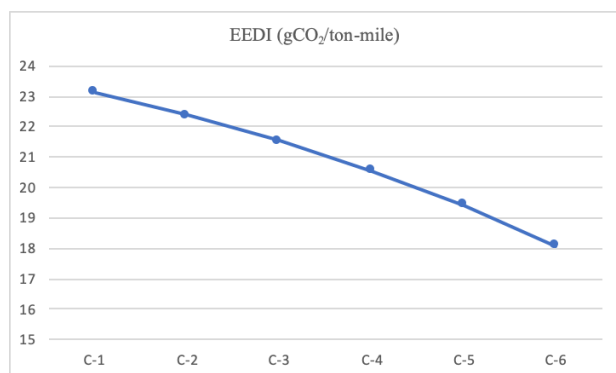
(gCO₂/ton.mile)(MEPC 66/21; IMO 2009; IMO 2012)

$$\text{EEDI}_{\text{required}} = (1 - \text{reduction factor}/100) \times \text{reference EEDI} = (1 - 10/100) \times 26,285 = 23,657$$

Since the reference EEDI is larger than the calculated attained EEDI, this ship can be considered as energy-efficient ship and emits less CO₂. This vessel doesn't exceed its EEDI value and doesn't need to be implemented EEDI reduction measures. Table 4 presents different calculation times according to different main engine load and Figure 5 shows EEDI (gCO₂/ton-mile) on M/V Leyla Kalkavan based on main engine load results. It can be concluded from calculations that the target ship meets the EEDI criteria.

Table 4. Calculation times according to main engine load on M/V Leyla Kalkavan

Main Engine Load	Calculation times	Main Engine Output (kW)	C _F	DWT	Speed (knots)
100% (max)	C-1	10.092	3,114	12.205	16
90%	C-2	9.083	3,114	12.205	15
80%	C-3	8.074	3,114	12.205	14
70%	C-4	7.064	3,114	12.205	13
60%	C-5	6.055	3,114	12.205	12
50%	C-6	5.046	3,114	12.205	11

Figure 5. EEDI (gCO₂/ton-mile) on M/V Leyla Kalkavan based on the main engine load.

It can be concluded from Table 4 and Figure 5, EEDI_{attained} value decreases with decreasing speed. It can also be seen that the main engine power (P_{ME}) decreases with decreasing speed. This means that speed reduction gives a better performance in terms of EEDI, the ship becomes more energy efficient and the ship emits less CO₂ emission. The ship definitely must navigate with the speed of 11 or 12 knots which is the economic speed.

Discussion and Conclusion

In this study, a container ship was analyzed in terms of energy efficiency performance. According to calculations, the ship was found an energy-efficient ship. The ship was built in 1997 and it wasn't under the mandatory regulation of MARPOL EEDI. Ship Energy Efficiency Management Plan (SEEMP) covers all types of ships so that SEEMP measures can be applied to keep the ship energy efficient. SEEMP measures can be implemented for better performance, and these measures will help to improve energy efficiency in the short, medium and long term, measures can be stated such as;

- alternative fuels such as LNG, LPG, gas oil can be used which will make 3-4% reduction,
- for the less resistance, hull optimization should be reviewed and underwater hull coatings and monitoring should be done periodically (4-5% reduction),
- speed reduction should be continued to get better EEDI performance (10-15% reduction)
- hull and propeller should be cleaned periodically (5-10% reduction),
- exhaust gas waste heat recovery of main and auxiliary engines should be implemented (15-20% reduction),

- weather routing such as avoiding rough seas and head currents should be implemented for voyage efficiency (4-6% reduction).

All these measures will help to keep the attained EEDI less than 23,125 gCO₂/ton.mile and the ship will be energy efficient. For the future, shipyards or ship designers should follow the EEDI implementations for the new energy-efficient ships. In the Turkish maritime trade fleet, generally all the container ships have the same specifications like age, size, tonnage, and speed. In general, there are some easy applications that all container ships can implement to maintain energy efficiency. It is evaluated that speed reduction application can be made easily in the beginning of these applications. The use of alternative fuels such as LNG, LPG, kerosene should definitely be encouraged. Boat and propeller cleaning should be done periodically, boat optimization and underwater hull coatings should be checked regularly.

Conflict of interest statement

I declare that I have no conflict of interest.

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