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Is It Possible to Achieve IMO Carbon Emission Reduction Targets at the Current Pace of Technological Progress?*

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Abstract

Purpose – The primary purpose of this study is to verify whether the target set out by the International Maritime Organization (IMO) for reducing carbon emissions from ships can be achieved by quantitatively analyzing the trends in technological advances of fuel oil consumption in the container shipping market. To achieve this purpose, several scenarios are designed considering various options such as eco-friendly fuels, low-speed operation, and the growth in ship size.

Design/methodology – The vessel size and speed used in prior studies are utilized to estimate the fuel oil consumption of container ships and the pace of technological progress and Energy Efficiency Design Index (EEDI) regulations are added. A database of 5,260 container ships, as of 2019, is used for multiple linear regression and quantile regression analyses.

Findings – The fuel oil consumption of vessels is predominantly affected by their speed, followed by their size, and the annual technological progress is estimated to be 0.57%. As the quantile increases, the influence of ship size and pace of technological progress increases, while the influence of speed and coefficient of EEDI variables decreases.

Originality/value – The conservative estimation of carbon emission drawn by a quantitative analysis of the technological progress concerning the fuel efficiency of container vessels shows that it is not possible to achieve IMO targets. Therefore, innovative efforts beyond the current scope of technological progress are required.

Keywords: Carbon Emissions, Container, Technological Progress, IMO
JEL Classifications: Q55, Q56, R41

1. Introduction

Starting with the Marine Pollution Treaty (MARPOL) in 1973, the International Maritime Organization (IMO) has discussed the reduction of air pollutant emissions and proposed various regulations on environmental protection. The Marine Environmental Protection Committee (MEPC), at its 72nd session held in 2018, adopted an initial strategy on the reduction of greenhouse gas (GHG) emissions from ships. To reduce GHG emissions from the shipping sector, they set targets to reduce the Carbon Intensity Indicator (CII), the average emission per transport unit, by at least 40% by 2030 compared to the 2008 level, and 70% by

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2050. For a long-term goal, it aims to reduce the total GHG emissions from the shipping sector by 50% by 2050 compared to the 2008 level.

Since 2013, the Energy Efficiency Design Index (EEDI) has been applied to newly built ships, and it is scheduled to be applied to existing ships from 2023 (MEPC 76). To meet this mandatory measure once it comes into effect, existing ships would have to lower their CII by 2% annually from 2024 to 2026 based on 2019. The number of the global fleet was 86,082 in 2012 when the EEDI regulation was not yet implemented, which is 86.6% of the 99,430 ships as of 2020. Existing ships ordered before 2012 are likely to fall short of the ratings required by the regulation. According to a survey by the Ministry of Oceans and Fisheries, only 15% (146 ships) of the 990 national-flag vessels satisfy the Energy Efficiency Existing Ship Index (EEXI) regulation (Ministry of Oceans and Fisheries, 2021).

As of 2020, container ships, the subject of this study, only account for 5.4% (5,400 vessels) of the world's total fleet. However, they cover 17% of global vessel travel as well as 25% of the total ship fuel consumption indicating a high proportion of fuel consumption compared to other ship types (Czermański et al., 2021). In addition, containers have a high cargo value among various maritime trades as they are responsible for transporting intermediate and final goods. They are also closely related to the real economy. Containers are a type of ship that can be markedly affected by environmental regulations; for example, if a carbon border tax promoted by the European Union (EU) is imposed, the high fuel consumption by containers will increase the burden on shipowners.

There are three main approaches to achieve carbon-neutrality in the shipping sector. The first involves a policy approach, which comprises the enactment of laws and regulations. In addition to the mandatory measures of the IMO to reduce the carbon intensity of ships, the EU confirmed the introduction of a carbon border tax in July 2021. A carbon neutrality law is being promoted in Korea, and voluntary participation through RE100 is taking place in the private sector. The second approach involves shipping companies attempting to reduce carbon emissions through changes in ship operation and navigation methods. The average container speed was recently lowered to around 14 knots compared to over 19 knots in 2008, thereby fuel efficiency has been improved. In addition, shipping companies are lowering CII by increasing vessel size and improving fuel efficiency by optimizing navigation routes. The third approach is a strategy to minimize ship emissions through technological progress. In addition to improvements in engine designs and hull shapes, fuel consumption can be further reduced by installing solar and wind-powered equipment. Furthermore, to achieve complete carbon neutrality, it is necessary to introduce zero-carbon ships that use hydrogen or ammonia as a marine fuel, and plans are simultaneously being promoted to produce such fuels through eco-friendly methods.

The primary purpose of this study is to verify whether the target set out by the IMO for reducing carbon emissions from ships can be achieved by quantitatively analyzing the trends in technological advances in fuel oil consumption in the container shipping industry. Fuel efficiency improvement for each year-of-built and EEDI regulation is added to the variables used in previous papers for consumption estimation. The inclusion of the year-of-built variable is one of the main points that differentiate this paper from existing research because the change in fuel efficiency along the timeline is interpreted as technological advances.

The structure of this paper is as follows: Chapter 2 reviews existing papers relating to IMO regulations and carbon emission; Chapter 3 estimates the fuel consumption of container ships by measuring the technological progress; Chapter 4 estimates carbon emissions by 2050, considering the technological progress; and Chapter 5 draws conclusions and implications of the study.

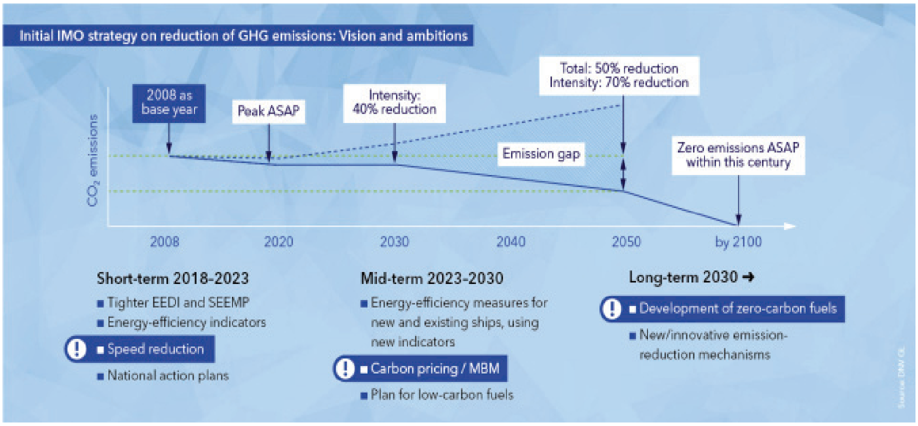
2. Literature Review on Carbon Emission in the Shipping Sector

2.1. IMO Regulations

IMO regulations on GHG emission started with the Resolution adopted at the IMO Assembly held in December 2003 and implemented from the 62nd session of the MEPC held in July 2011. The MEPC adopted the Resolution on ship energy efficiency regulations at its 62nd session, introducing the EEDI for new ships and Ship Energy Efficiency Management Plan (SEEMP) under MARPOL Annex VI Regulations. It also adopted the Resolution on data collection on ships' fuel consumption at the 70th session and a long-term roadmap for reducing the total GHG emissions at the 72nd session in 2018.

The Resolution adopted at the 72nd session of the MEPC states that the CII, the fuel efficiency index of the shipping sector, should be improved by 40% or more by 2030, and the total GHG emissions from the shipping sector should be reduced by 50% compared to 2008 level. The ultimate goal is to achieve zero GHG emissions by 2100. The MEPC confirmed at its 76th session that the fuel efficiency for existing ships should be regulated from the end of 2022. Vessels of 5,000 G/T or more, which are currently operating, are required to record the method of CII calculation to be applied from 2023 in the SEEMP by the end of 2022. The attained CII rating ranging from A to E should be calculated based on the annual fuel consumption performance reporting system i.e. Data Collection System (DCS). For ships that record an E rating for three consecutive years, a corrective energy efficiency improvement plan must be submitted. Furthermore, these ships can only operate if they are additionally equipped with power-limiting or energy-reducing devices. The CII regulations have become increasingly strict each year; by 2023, ships are required to reduce GHG emissions by 5%compared to the 2019leveland by an additional 2% each year until 2026.

Fig. 1. The IMO Goal to Reduce GHG Emissions



Source: DNV·GL (2019).

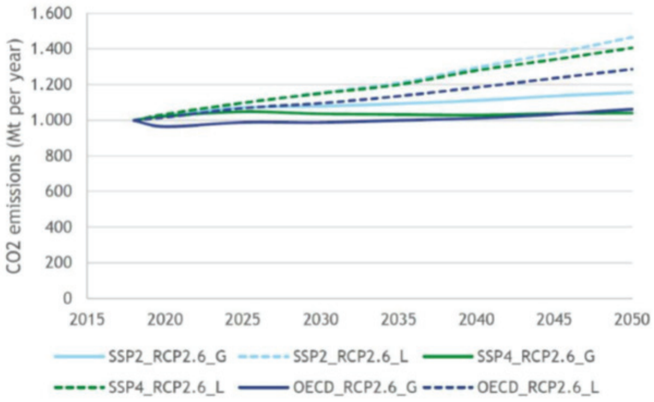
2.2. Literature on Carbon Emissions in the Shipping Sector

2.2.1. Carbon Emission Study Conducted by the IMO

The IMO has researched carbon emissions since 2000, and the latest outcome was the 4th IMO Greenhouse Gas Study published in 2020. This study estimates GHG emissions using the bottom-up and top-down approaches. The bottom-up approach estimates transport demand using GDP, population growth, and socio-economic scenarios; subsequently, the fuel consumption is estimated to calculate GHG emissions by predicting the fleet based on the size of the ship and by estimating ship fuel consumption using fuel efficiency. Consequently, various factors such as GDP, population, and urbanization are used and the socio-economic path as presented in studies by van Vuuren et al. (2011) and Riahi et al. (2017) is also applied for the construction of five energy scenarios. The top-down approach derives estimations using the sales volume of fuel oil used in shipping, the methodologies and assumptions of which are the application of the method used by the International Energy Agency (IEA, 2020).

According to the IMO (2020), GHG emissions are projected to increase from 1 billion tons in 2018 to up to 15 billion tons in 2050. This is an increase of 0-50% and 90-130% compared to 2018 and 2008 levels respectively.

Fig. 2. Projections of GHG Emissions by the IMO



Source: IMO (2020), p. 37.

2.2.2 Literature on Ship Fuel Consumption and Carbon Emissions

Machine learning is being used to estimate carbon emissions using fuel consumption. Wang et al. (2018); Uyanik, Karatuğ, and Arslanoğlu (2020); and Moreira, Vettor, and Guedes Soares (2021) make estimations using Lasso, Support Vector Regression (SVR), and Artificial Neural Networks (ANN). In most studies, including Meng, Du, and Wang (2016), ship length, width, speed, and wave height are used to estimate significant variables. Le, L. T. et al. (2019) derives an estimation model using the speed and operating time for five ship classes, which are identified from operation data of 100 to 143 container ships that operated between 2012 and 2016. Lu, Turan, and Boulougouris (2013) predict that improving energy efficiency through operational optimization would reduce GHG emissions. Accordingly, a novel fuel consumption estimation formula is derived based on the modeling suggested by Kwon (2008) for Suezmax tankers.

Johansson, Jalkanen, and Kukkonen (2017) present the Ship Traffic Emission Assessment Model that can estimate pollutant emissions (nitrogen oxide, particulate matter, and GHG) by continent and size by analyzing 8 billion AIS data from 90,000 ships as of 2015. The result shows that bulk carriers and tankers emit 4.7g and 6.1g of carbon per ton·km respectively and containers emit 9.7g. Psaraftis and Konovas (2009) estimate the GHG emissions of the global merchant fleet (bulk, tanker, container, LNG/LPG, and Ro-Ro ship) using the ship data of Lloyds-Fairplay. They show that 840 million tons of GHGs have been emitted as of 2007, assuming an annual operation of 320 days.

Cariou (2011); Lindstad, Asbjørnslett and Strømman (2011); and Chang and Chang (2013) study the reduction of GHG emissions through a low-speed operation. Lindstad, Asbjørnslett and Strømman (2011) suggest that the amount of GHG emissions could be reduced by 62% when the container ship speed (relative to the design speed) is reduced by 67%. Chang and Chang (2013) measure the change in carbon emissions when decelerating the average ship speed (14.4 knots) by 10/20/30%, resulting in the decrease of carbon emission by 19/36/56% respectively.

Gilbert (2014) and Bouman et al. (2017) introduce technologies that can minimize GHG emissions in the shipping sector. Notably, Bouman et al. (2017) identify six major fields (hull design, vessel enlargement, power and propulsion, speed, fuel, weather, and schedule) and 22 sub-fields where GHG emissions can be minimized. The results of reduction estimation indicate that a significant reduction in GHG emissions is impossible unless eco-friendly fuels such as hydrogen and ammonia are used.

2.2.3 Literature on Applications of Technological Changes

The 3rd and 4th IMO Greenhouse Gas Studies published in 2014 and 2020 consider technological progress. The 3rd IMO Greenhouse Gas Study (2014) collectively reflects the effects of EEDI application from Phase 0 to Phase 3. Since EEDI has only been applied to new ships built since 2013, the absence of related information is complemented by assumptions regarding fuel consumption reduction.

Table 1. Fuel Consumption Reduction by EEDI Application

Reduction relative to original baseline	Reduction relative to baseline, taking SFC into account
0%	-7.5%
10%	2.5%
20%	12.5%
30%	22.5%

Note: SFC refers to specific fuel consumption.
Source: IMO (2014), p. 280.

The 4th IMO Greenhouse Gas Study (2020) applies technological progress that is divided into 16 groups. The projections for 2050 are made based on scenarios regarding penetration rates of new technologies in the areas of alternative fuels, weight-lightening, and engine improvements.

The IEA (2020) projects that carbon emissions would be reduced by more than 60% by using new technologies, including eco-friendly fuels, that are not currently commercialized. Looking at the relative contribution to carbon emission reduction, the reduction effect of technological improvement and eco-friendly fuel is greater than that of operational efficiencies such as fleet optimization and low-speed operation.

3. Estimation of Technological Progress (Methodology)

3.1. Data

The data used to estimate the fuel consumption is the container ship database provided by IHS as of 2019. It includes various data such as IMO number, ship size (e.g., length), number of loadable containers, country of construction, shipyard, fuel consumption, design speed, and engine type. As of 2019, about 5,300 container ships are in operation, of which information on 5,260 ships is included in this DB (Clarkson, 2021). However, the fuel consumption records of some ships are missing in this DB hence, data for 4,744 ships are used for the study.

The descriptive statistics on the fuel consumption (ton/day), the number of loadable containers (TEU), design speed for ship operation (knots), and year of built are shown in Table 2. The statistics on the EEDI variable are not presented as they are dummy variables to show whether the ships are built after 2015. The average daily fuel consumption is 113 tons, and the average number of loadable containers is 4,391TEU, the average design speed is 21.2 knots, and the mean year of construction is 2007. The standard deviation of the number of loadable containers is found to be very large at 3,971.5 due to the ship size increases.

The design speed shows the highest correlation with ship fuel consumption (0.8555), followed by the number of loadable containers (0.8147) and the year of built (0.2214).

Table 2. Descriptive Statistics by Variables

Variables	Average	Maximum	Minimum	Standard deviation
Fuel consumption (ton/day)	112.9	326.1	4.3	78.4
Number of loadable containers (TEU)	4,391.1	21,237.0	95.0	3,971.5
Design speed (knots)	21.2	10	27.5	3.04
Year of built	2006.9	2019	1971	6.49

Table 3. Correlation between Variables

Variables	Fuel consumption	Number of loadable containers	Design speed	Built year
Fuel consumption	1			
Number of loadable containers	0.8147	1		
Design speed	0.8555	0.5594	1	
Built year	0.2214	0.4085	0.1585	1

3.2. Research Model

Studies on carbon emissions in the shipping sector generally estimate the fuel consumption based on ship size and speed and occasionally use actual operational data such as weather data e.g., wind, wave height. Wang et al. (2018) and Le et al. (2020) estimate fuel consumption using variables such as ship size and speed. Moreira and Vettor, Guedes Soares (2021), and Uyanik, Karatuğ, and Arslanoğlu (2020) use machine learning to improve the accuracy of estimation.

In addition to ship speed and size which have been used in previous studies, the estimation in this study considers the pace of technological progress and EEDI with the year of construction. The reduction rate of fuel consumption according to the year of construction of the ship can be interpreted as 'technological progress'. The EEDI variable is applied as a dummy variable because the IMO mandated a 10% reduction in fuel efficiency for all ships built after 2015. Tokuşlu, A. (2020) includes the EEDI variable in estimating the reduction of fuel consumption. This research expands the scope of container vessels to the entire container fleet built since 2015 while Tokuşlu, A. (2020) restricted his analysis to the operation data of one vessel.

$$\ln(fuel\_consumption) = \beta_1 + \beta_2 \cdot \ln(ship\_speed) + \beta_3 \cdot \ln(ship_{size}) + \beta_4 \cdot built\_year + \beta_5 \cdot dm\_EEDI + \varepsilon$$

- fuel_consumption: Amount of fuel consumed by the ship (MT)
- ship_speed: Design speed for ship operation (KTS)
- ship_size: Number of loadable containers (TEU)
- built_year: Year of construction
- EEDI: Ships subject to the regulation (Phase 1: ships built after 2015)

3.3. Empirical Results

3.3.1. Results of Linear Regression Analysis

Two models are applied to review the difference in variables before and after applying EEDI. The result shows that the construction year of the ship affects fuel consumption. The fuel consumption changes 0.8% on the year of construction in Model 1, which excludes the EEDI variable, and 0.57% in Model 2. Since the main object of this study was to estimate the pace of technological progress, the fuel consumption reduction coefficient of 0.57% derived from Model 2 was used to estimate the future carbon emission of container ships.

Speed has the most significant influence on the fuel consumption of container ships; the fuel consumption increased by 2.5% when the speed increases by 1%. The ratio is close to the 'Cube Rule'. The fuel consumption increases by 0.5% when the size of the ship increases by 1%, indicating that the scale economy is functioning. The influence of the EEDI variable applied to ships built after 2015 is estimated to be 10.8%, which indicates that the ratio of 10% in the first phase of EEDI regulation is abided by.

Linear regression analysis requires independence among variables because the reliability decreases if the correlation is high. Therefore, multicollinearity between variables included in the model must be verified, for which the most commonly used method is Variance Inflation

Factor (VIF) analysis. The result of multicollinearity verification shows that the values of the VIF of all variables are below 3, confirming no problem. The criteria for multicollinearity is a VIF of 10 or higher.

Table 4. Linear Regression Analysis Results

Variable	Model 1	Model 2
Constant	8.696912*** (11.76717)	4.292152*** (05.279854)
ship_speed	2.553202*** (116.4059)	2.492840*** (112.4754)
ship_size	0.501157*** (128.8189)	0.505501*** (131.3665)
built year	-0.00799*** (-21.7976)	-0.005712*** (-14.05790)
dm_EEDI		-0.108156*** (-12.16762)
$\bar{R}^2$	0.96659	0.967595

Note: *** means coefficients are significant at 1% level.

Table 5. Multicollinearity Verification Results (VIF)

Variables	VIF value
Constant	-
ship_speed	2.61
ship_size	2.92
built year	1.61
dm_EEDI	1.42

3.3.2. Results of Quantile Regression Analysis

In addition to the linear regression analysis for the estimation of all ships, quantile regression analysis is used to analyze how the coefficients vary from small to large vessels.

Unlike linear regression analysis using the mean, quantile regression analysis uses the median value. While linear regression analysis minimizes the prediction error (e_i)by minimizing $\sum_i e_i^2$ using the ordinary least squares (OLS), quantile regression minimizes $\sum_i |e_i|$. This study used a linear programming method for optimization, in the same way as the least-squares method or the most-likelihood estimation method. The q^{th} quantile regression estimator $\hat{\beta}_q$ is minimized for the following objective function β_q.

$$Q(\beta_q) = \sum_{i:y_i \geq x_i' \beta}^{N} q|y_i - x_i' \beta_q| + \sum_{i:y_i < x_i' \beta}^{N} (1-q)|y_i - x_i' \beta_q|$$

This method has several advantages. First, estimates from quantile regression analysis can lead to more robust estimates than linear regression which responds significantly to outliers and is inefficient when the dependent variable is not normally distributed. Second, various characteristics that affect variable properties can be obtained. This study seeks the difference in the degree of the influence of each variable, depending on the quantile of fuel consumption. Third, unlike the least-squares method, the consistency of the quantile regression estimator is not dependent on the presence of a conditional mean. Fourth, since quantile regression is not affected by monotonic transformation, the inverse transformation can be used to interpret the results (Cameron, A. C. and P. K. Trivedi, (2010)).

Quantile regression analysis results reveal that the influence of the speed, which has the most significant influence on fuel consumption, gradually decreased from the 1st quantile (low fuel consumption) to the 9th quantile (high fuel consumption). On the other hand, the influence of ship size increases as the quantile increases. The effect of the built year (as a coefficient for technological progress) increases as the size of the ship increases. The effect of the pace of technological progress is only 0.44% in the 1st quantile, which doubles to 0.86% at the 9th quantile. This shows that a relatively more significant improvement in the technological progress for large ships than that for small ships results in higher fuel efficiency for large ships.

Table 6. Results of Quantile Regression Analysis

Ship size	**1st quantile**	**2nd quantile**	**3rd quantile**
Constant	0.444922	-2.19143**	0.425707
ship_speed	2.991615***	3.006738***	2.867138***
ship_size	0.4369***	0.432543***	0.460277***
built year	-0.00436***	-0.00303***	-0.00421***
dm_EEDI	-0.1361***	-0.1294***	-0.1346***
$\bar{R}^2$	0.822464	0.832568	0.843287
Ship size	**4th quantile**	**5th quantile**	**6th quantile**
Constant	2.242242***	2.869113***	3.094442***
ship_speed	2.541143***	2.430732***	2.283524***
ship_size	0.506917***	0.524525***	0.542092***
built year	-0.00478***	-0.00498***	-0.00492***
dm_EEDI	-0.17756***	-0.12333***	-0.12911***
$\bar{R}^2$	0.848418	0.847616	0.845609
Ship size	**7th quantile**	**8th quantile**	**9th quantile**
Constant	5.640926***	6.564444***	10.95583***
ship_speed	2.200705***	2.037928***	2.07712***
ship_size	0.554463***	0.572928***	0.565929***
built year	-0.0061***	-0.00637***	-0.00857***
dm_EEDI	-0.05812***	-0.04288***	-0.02882**
$\bar{R}^2$	0.836597	0.823849	0.793028

Note: *p<0.1, **p<0.05, ***p<0.001.

The change in the coefficient value for each quantile shows the change in the variables according to the fuel consumption. The coefficient values of ship speed and year of construction decrease as the quantile increases, while the coefficient values of ship size and EEDI variables increase as the quantile increases.

4. Estimation of Carbon Emissions by Container Fleet

Considering the IMO regulations have been applied since 2008, carbon emissions are estimated using the formula for estimating fuel consumptions as presented in Chapter 3. As of 2008, a total of 4,398 container ships were operated with an average operating speed of 19 knots (Clarkson, 2021). The average number of sea days is 250 days as applied by Czermański et al. (2021), and the fuel consumption during berthing and anchoring is applied as 6.0% of that of the sea days following Comer et al. (2017). When estimating carbon emissions based on the estimated fuel consumption, the suggested conversion factor of 3.114 is applied following IMO (2020). As a result, as of 2008, the container ship used 74.03 million tons of fuel and emitted 230 million tons of carbon.

Table 7. Carbon Emission Estimation of Container Fleet as of 2008

Category	Less than 3,000TEU	3,000-7,999TEU	8,000-15,000TEU	15,000TEU or more
Daily fuel consumption based on fleet, 2008	47.3	87.4	119.4	166.7
Number of ships in operation	3,096	1,131	164	7
Year of construction	1998	2002	2005	2007
Total fuel consumption (navigation + berthing/ anchoring)	74,028			
Carbon emission (thousand tons)	230,523			

The later the newbuilding of ships, the better the efficiency of fuel consumption because of the application of EEDI and technological progress. As of the end of 2019, the mean year of construction of 3,000-7,999TEU-class ships is 2007, and the average size is 4,909TEU. The fuel consumption of these ships is estimated at 65.8 mt/day. However, that of ships built in 2030 is expected to decrease to 45.1 mt/day and those built in 2050 to 38.1 mt/day. Such an improvement is similar for all types of ships, and the fuel efficiency of ships built in 2050 is expected to be improved by 30% from the 2020 level.

Owing to technological progress in ships, the amount of carbon emitted by one container ship is expected to decrease to below-50% in 2050 compared to 2008 levels. On the other hand, as of 2019, the number of container ships increased by 20.7% and the capacity by 101.9%, compared to 2008 levels. For simplicity in estimating carbon emissions, it is assumed that the container fleet in 2019 remains the same throughout 2050, and efficiency increases annually. The result shows that carbon emissions are estimated to decrease by 35.2% in 2050 compared to 2008 levels. In other words, if the current pace of technological progress is maintained, it is not possible to meet the IMO target of reducing carbon emissions by 50% compared to the 2008 level. Moreover, since the analysis assumes the fleet is unchanged, it will be even harder to satisfy the IMO carbon emission regulations with the fleet growth in the future.

Table 8. Projection of Fuel Consumption and Carbon Emission

Unit: tons, thousand tons

Category	Less than 3,000TEU	3,000-7,999TEU	8,000-15,000TEU	15,000TEU or more	Carbon emissions (thousand tons)
2008	47.3	87.4	119.4	166.7	230,523
2020	28.8	54.9	80.4	107.8	214,568
2030	23.7	45.1	66.4	89.4	177,000
2040	22.1	41.9	61.7	83.1	164,540
2050	20.0	38.1	56.0	75.4	149,363

Note: Assuming 17 knots of speed, the fuel consumption for each ship type is calculated based on the average size of each ship class. Fuel consumption by type is applied when estimating carbon emissions for 2020, 2030, 2040, and 2050.

Source: Author's estimation.

5. Conclusion

In this study, first, the current technological progress is quantitatively analyzed and applied to estimate future carbon emissions. The empirical analysis demonstrates that the annual technological progress of container ships is estimated to be 0.57%. However, the IMO GHG emission regulations would not be satisfied with the current pace. Even under the assumption that the number of container ships in 2019 remains the same until 2050 while technological progression in fuel efficiency sustains, the decrease in carbon emissions was limited to 35.2% compared to 2008 levels. Second, the results of quantile regression analysis show the effects of difference in technological progress on the fuel consumption level of the ships; the higher the fuel consumption, the higher is the improvement in fuel efficiency. This indicates that CII would markedly increase as the enlargement of ships progressed. Third, using the ship DB, a fuel consumption estimation formula is devised based on the ship size, speed, and year of construction, enabling the estimation of fuel consumption and carbon emissions of the container fleet in 2008, leading to the estimation that the carbon emissions would be reduced by 2050. Fourth, it is confirmed that the EEDI regulations, which were initiated in 2013, have been applied to container fleets. This study, which performs the EEDI analysis on the entire container fleet, is significant because its results can be compared to the results reported by Tokuşlu, A. (2020), which reviews the EEDI satisfaction of one container ship.

However, this study has some limitations. The carbon emission projection is underestimated because the size of container fleets between 2020 and 2050 is anchored to the 2019 level. In addition, carbon emissions are estimated using the specifications of the vessel, while the possible differences caused by the distance and speed of the ship are not reflected. This research can be meaningfully expanded in the future when scenario analyses and other models such as system dynamics or AI models are employed.

Recently, large shippers, such as Amazon and IKEA, announced that they would transport cargo using zero-emission vessels from 2040 (Lloyd's List, 2021). Currently, "how" is more important than "how much" in ocean transportation. Recently, the selection criteria for large forwarders as well as shippers include the fleet operation with eco-friendly ship certifications or efforts against GHG emissions. Gilbert (2014) warns that short-sighted and weaker regulations may weaken their enforcement power by offering various alternatives to shipping companies. Since IMO regulations are challenging to conform to at the current pace of technological progress, it is time for shipping companies to make additional changes to achieve carbon neutrality.

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