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A Study on the Impact of Slow Steaming on Containership Operations under the Carbon Intensity Indicator Regulation

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Abstract : *As there is growing concern about the environmental impact of greenhouse gas emissions from ships, the International Maritime Organization (IMO) has introduced several regulations targeting reductions in carbon dioxide emissions of 50% by 2050. This study pays particular attention to the carbon intensity indicator (CII) and investigates the impact of slow steaming, one of the short-term measures in the regulation, on containership operations. To this end, a dataset of 8 containerships with various ages and sizes was collected. Based on operation data in 2021, the CII ratings of the containerships were estimated in the business-as-usual scenario for the 2023-2030 period. Then, the speed reductions required to keep the minimum CII rating were calculated for individual containerships. Finally, working day losses resulting from the speed reductions were calculated. The findings in this study were threefold. First, it was found that containerships will undergo degradation in the CII rating every 3 or 4 years without slow steaming. Second, a speed reduction of 2 knots between 2023 and 2030 is required to keep the minimum CII rating. Finally, speed reductions result in the loss of as many as 6 or 7 working days per year.*

Key words : *slow steaming, carbon intensity indicator, CO2 emissions, container shipping, IMO*

1. Introduction

It is traditionally perceived that shipping is the most cost-efficient mode of transport as it has the lower unit cost than road, rail and air transport. A similar argument in the environment protection context is also applicable: shipping is the most energy-efficient (or, alternatively eco-friendly) mode of transport as it consumes less fuel per unit than others (Chapman, 1989).

However, shipping, as a whole, is one of the most significant sources of greenhouse gas emissions especially accounting for, on average, 3.1% of annual global CO_2 emissions for the period 2007-2012 (Smith et al., 2015). This is largely attributed to the fact that the vast majority of trade flows between countries is serviced by maritime transport, which implies that the growth in international trade for the past several decades has increased demand for shipping, resulting in large amount of fossil fuel consumption and CO_2 emissions. According to the study of Buhaug et al. (2009), without further environmental regulations or policies, it is estimated that emissions from ships could increase by 200% to 300% by 2050 compared to the emissions in 2007 as a result of the growth in international trade.

Against this background, the IMO has set an ambitious target of the reduction of CO_2 emissions from maritime transport by, at least, 40% and 50% by 2030 and 2050, respectively in comparison to 2008 (IMO, 2018). Following up the goal, in June 2021, as an initial strategy of reduction of CO_2 emissions, the IMO adopted two regulations that entered into force from 2023: namely, the Energy Efficiency Existing Ship Index (EEXI) and the CII (IMO, 2021a). While the EEXI assesses the energy efficiency of a ship's technical design, the CII measures the fuel-efficiency of a ship's operation (Yuan et al., 2023).

In response to the environment regulations, the shipping industry considers a number of measures to reduce emissions from ships and, according to Farkas et al. (2021), those can be broadly categorized into four groups: technical measures, operational measures, alternative fuels and renewable energy sources. Among them, this research pays particular attention to slow steaming, one of the operational measures adopted on the rationale that speed reduction can save fuel consumption resulting in lower CO_2 emissions.

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Given the 'cubic law', a rule of thumb estimation indicating that the fuel consumption is proportional to a ship's speed to the power of 3 at its design speed (Adland et al., 2020), it is quite compelling that slowing down of a ship can significantly reduce CO2 emissions. Therefore, it is widely accepted that slow steaming is one of the most-effective short-term measures to address environmental regulations (Cariou, 2011; Lindstad et al., 2011).

In this regard, this study investigates the impact of slow steaming on containership operations under the CII regulations. Specifically, under the business-as-usual scenario, this study simulates the CII ratings of containerships with various ages and sizes for the period 2023-2030. Then, this study calculate the speed reduction required to keep the CII rating and the corresponding losses of working days.

The rest of this study is structured as following: Section 2 reviews the current status of emissions from containerships, the CII regulation and relevant research. Section 3 describes the dataset and the methodology employed in this study. Section 4 presents the simulation results. Finally, Section 5 discusses and concludes this study.

2. Research Background and Literature Review

2.1 CO2 emissions from containerships and slow steaming

There are two important reasons that this research highlights the container shipping sector. First, the liner sector is one of the largest sources of CO2 emissions in shipping. Although the containership sector takes 13.5% of the existing fleet in terms of the deadweight tonnage (DWT) as of December 2023, its fleet has increased by 7.4%, on average, every year during 1996-2023, making it faster-growing sector than the bulker and the tanker with the annual growth of 5.3% and 3.4%, respectively.[1] Furthermore, as containerships carry semi-finished or finished goods that are more time-sensitive, they sail at faster speed than other ship types. According to the data of Clarksons Research, the average speed of containerships for the period 2008-2023 is 15.4 knots, while those of the bulk carriers and crude tankers are 11.8 knots and 12.1 knots, respectively. Therefore, it is estimated that the total CO2 emissions from containerships is 205 million tons in 2012, second to none of other ship types (Smith et al., 2015).

Second, the trade-off between slow steaming for CO2 reduction and service reliability for supply chain management is especially significant for container shipping. On the one hand, shipping service providers can benefit from speed reduction as it contributes to saving fuel consumption and operating costs as well as abatement of CO2 emissions from ships. From the shippers' perspective, on the other hand, slow steaming could result in less frequency of calls and longer transit time, which ultimately leads to the increase in inventory costs (Maloni et al., 2013, Tran and Lam, 2022).

2.2 CII Regulation

The CII measures the average CO2 emissions of a ship in the transportation workload and the CII rating is assigned by comparing the attained annual operational CII (Attained CII) and the required annual operational CII (Required CII). The Attained CII is obtained from the ratio of the CO2 emissions from a ship to the transport workload in a year as following:

$$Attained\ CII = \frac{M}{W} = \frac{\sum_j FC_j \times C_{Fj}}{C \times D_t} \tag{1}$$

where, M is the mass of CO2 emissions which is the product of the fuel consumption of the fuel type j (FC_j) and the CO2 emissions conversion factor (C_{Fj}). W is the transport workload which is the product of a ship's capacity (C, DWT for containerships) and the total sailing distance (D_t).

For the calculation of the Required CII, the CII reference line (CII_{ref}), a curve describing the median value of Attained CII, should be obtained first as following:

$$CII_{ref} = \alpha \times C^{\beta} \tag{2}$$

where, C is a ship's capacity. α and β are parameters obtained from regression analysis. For containerships, they are 1984 and 0.489, respectively (IMO, 2022a).

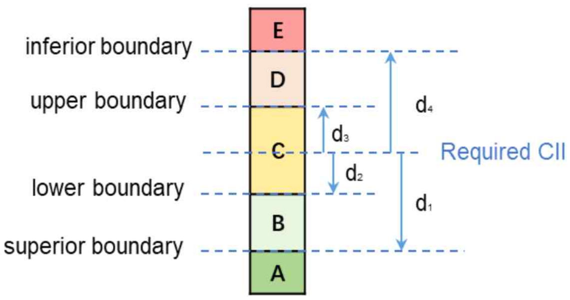
1) Data compiled from Clarksons Research.

Then, the Required CII is obtained from the following equation:

$$Required\ CII = CII_{ref} \times (1 - Z/100) \quad (3)$$

where, Z is a reference to the reduction factors. The values are 5% in 2023, 7% in 2024, 9% in 2025, 11% in 2026, respectively, relative to 2019 and those in from 2027 will be decided after assessing the effectiveness of the regulation (IMO, 2021b)

The CII rating is assigned from A (the best rating) to E (the worst rating) by comparing the Attained CII and the product of the Required CII and the boundary value as in Fig. 1. The boundary values for containerships assigned by the IMO (2022b) are 0.83 for d_1, 0.94 for d_2, 1.07 for d_3 and 1.19 for d_4, respectively.



$$\text{superior boundary} = \exp(d_1) \cdot required\ CII$$
$$\text{lower boundary} = \exp(d_2) \cdot required\ CII$$
$$\text{upper boundary} = \exp(d_3) \cdot required\ CII$$
$$\text{inferior boundary} = \exp(d_4) \cdot required\ CII$$

Fig. 1 Calculation of CII ratings
Source : IMO (2022b).

2.3 Literature Review

Despite the significant role of slow steaming in reducing CO2 emissions from ships, the questions on, especially, its sustainability, profitability and viability have been addressed in the previous literature. It is generally agreed that while slow steaming is one of the most effective short-term responses to environment regulations, further measures should be in line with its implementation.

A strand of research argues that the viability of slow steaming depends on several conditions. Farkas et al. (2023) report that the benefits from speed reduction of post-Panamax containerships differ depending on the sailing routes, the location and the month. Similarly, Degiuli et al. (2021) show that the reduction in fuel consumption and CO2 emissions can vary by water conditions (i.e. in calm water and in waves). In addition, Cariou (2011) demonstrates that, for containerships servicing main trade routes, slow steaming can be sustainable only when the bunker price reads between $350 and $400.

Another research stream examines the ways to improve the effectiveness of slow steaming by mixing auxiliary measures. Eide et al. (2013) document that CO2 reduction from shipping can be achieved in a more cost-effective way when operational measures (including slow steaming) are implemented with the use of eco-friendly fuels. Moreover, antifouling coatings (Farkas et al., 2021) and wind propulsion (Mander, 2017) are proposed as auxiliary measures for slow steaming.

Finally, the trade-off relationship between slow steaming and service frequency is also extensively investigated. Ferrari et al. (2015) discusses the changes expected in the container shipping sector triggered by slow steaming, such as the reduced number of port calls and the emergence of express (or premium) services. In addition, Wong et al. (2015) propose a utility-based model of containership operations optimizing the fuel consumption, transit time and sailing distance.

While a number of previous studies provide valuable insights regarding environment-friendly operation of containerships with speed reduction, the majority of them rely on rather several assumptions lacking the support of the dataset of actual operation. Furthermore, domestic research has highlighted environment-friendly shipping by utilizing alternative fuels (Anh et al., 2023) and forecasting fuel consumption (Kim et al., 2019), or policy suggestions (Yang et al., 2019). Therefore, findings providing more realistic implications can be obtained by examining containership operations in the real-world business. Furthermore, as most of previous studies focus on a specific size of containerships or a specific sailing route, there is a need for findings based on a variety of ship characteristics. Therefore, this study investigates the impact of slow steaming on operation of containerships with various ages and sizes.

3. Data and Methodology

The impact of slow steaming is examined for eight containerhips operated by one of the global liner shipping companies. As seen in Table 1, the size (in terms of DWT) and the age vary by ships. Moreover, the Attained CII, the CII_{ref}, the expected CII rating (as of 2023) are also reported based on their actual operations in 2021. The calculation is based on the consumption of individual fuel types. On average, fuel consumption for heavy fuel oil, lighe fuel oil and marine gas oil are 14,165 tons, 2,846 tons and 1,051 tons, respectively.

Table 1 Size, age and CIIs of sample containerships

Ship	DWT	Built Year	CII		
			Attained	ref	Rating
A	63,254	2008	8.35	8.91	C
B	72,982	2009	8.96	8.31	D
C	80,108	2009	8.03	7.94	C
D	99,123	2008	7.87	7.15	D
E	134,419	2018	5.20	6.16	B
F	146,046	2014	5.60	5.92	C
G	160,927	2021	4.54	5.64	B
H	232,606	2020	4.15	4.71	B

Assuming the 270 sailing days per year (estimation based on actual operation in 2021), this study calculate the expected CII ratings of containerships according to the ship speed for the period 2023-2030. Then, the average ship speed to maintain the minimum CII rating is calculated for the same period. As either 'D' in three consecutive years or 'E' in a single year requires shipping companies to implement following-up measures to reduce CO_2 emissions, it is generally agreed that they should maintain 'C'. Finally, this study estimates the losses of working days resulting from the speed reduction to maintain the minimum CII ratings.

4. Results

Fig. 2 depicts the CII ratings by ship speed (between 13 knots and 18 knots) for individual containerships during 2023-2030. It is quite evident that shipping companies should limit the speed of their ships to keep the minimum CII ratings. Specifically, as the reduction factor (Z in Eq. (3)) will increase by 2% during 2023-2026, the CII ratings of individual containerships undergo degradation through the period. In addition, it is generally observed that older containerships (Ship A to Ship D) can maintain 'C' only when the sailing speed below 17 knots. Therefore, it is compelling that containerships should reduce their speeds to comply with the CII regulation.

Ship A

<table>
<tr><th>Year / Speed</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>13</td><td colspan="6">A</td><td colspan="2">B</td></tr>
<tr><td>14</td><td colspan="4">A</td><td colspan="3">B</td><td>C</td></tr>
<tr><td>15</td><td colspan="5">B</td><td colspan="3">C</td></tr>
<tr><td>16</td><td>B</td><td colspan="5">C</td><td colspan="2">D</td></tr>
<tr><td>17</td><td colspan="3">C</td><td colspan="3">D</td><td colspan="2">E</td></tr>
<tr><td>18</td><td colspan="3">D</td><td colspan="5">E</td></tr>
</table>

Ship B

<table>
<tr><th>Year / Speed</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>13</td><td colspan="3">A</td><td colspan="4">B</td><td>C</td></tr>
<tr><td>14</td><td colspan="4">B</td><td colspan="4">C</td></tr>
<tr><td>15</td><td colspan="5">C</td><td colspan="3">D</td></tr>
<tr><td>16</td><td>C</td><td colspan="4">D</td><td colspan="3">E</td></tr>
<tr><td>17</td><td>D</td><td colspan="7">E</td></tr>
<tr><td>18</td><td colspan="8">E</td></tr>
</table>

Ship C

<table>
<tr><th>Year / Speed</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>13</td><td colspan="2">A</td><td colspan="4">B</td><td colspan="2">C</td></tr>
<tr><td>14</td><td colspan="4">B</td><td colspan="4">C</td></tr>
<tr><td>15</td><td colspan="5">C</td><td colspan="3">D</td></tr>
<tr><td>16</td><td>C</td><td colspan="4">D</td><td colspan="3">E</td></tr>
<tr><td>17</td><td>D</td><td colspan="7">E</td></tr>
<tr><td>18</td><td colspan="8">E</td></tr>
</table>

Ship D

<table>
<tr><th>Year / Speed</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>13</td><td colspan="3">A</td><td colspan="4">B</td><td>C</td></tr>
<tr><td>14</td><td colspan="4">B</td><td colspan="4">C</td></tr>
<tr><td>15</td><td colspan="5">C</td><td colspan="3">D</td></tr>
<tr><td>16</td><td colspan="2">C</td><td colspan="4">D</td><td colspan="2">E</td></tr>
<tr><td>17</td><td colspan="2">D</td><td colspan="6">E</td></tr>
<tr><td>18</td><td colspan="8">E</td></tr>
</table>

Ship E

<table>
<tr><th>Year / Speed</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>13</td><td colspan="8">A</td></tr>
<tr><td>14</td><td colspan="8">A</td></tr>
<tr><td>15</td><td colspan="5">A</td><td colspan="3">B</td></tr>
<tr><td>16</td><td colspan="5">B</td><td colspan="3">C</td></tr>
<tr><td>17</td><td>B</td><td colspan="5">C</td><td colspan="2">D</td></tr>
<tr><td>18</td><td colspan="2">C</td><td colspan="4">D</td><td colspan="2">E</td></tr>
</table>

Ship F

<table>
<tr><th>Year / Speed</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>13</td><td colspan="8">A</td></tr>
<tr><td>14</td><td colspan="6">A</td><td colspan="2">B</td></tr>
<tr><td>15</td><td colspan="2">A</td><td colspan="4">B</td><td colspan="2">C</td></tr>
<tr><td>16</td><td colspan="4">B</td><td colspan="3">C</td><td>D</td></tr>
<tr><td>17</td><td colspan="4">C</td><td colspan="4">D</td></tr>
<tr><td>18</td><td colspan="5">D</td><td colspan="3">E</td></tr>
</table>

Ship G

<table>
<tr><th>Year / Speed</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>13</td><td colspan="8">A</td></tr>
<tr><td>14</td><td colspan="5">A</td><td colspan="3">B</td></tr>
<tr><td>15</td><td>A</td><td colspan="5">B</td><td colspan="2">C</td></tr>
<tr><td>16</td><td>B</td><td colspan="5">C</td><td colspan="2">D</td></tr>
<tr><td>17</td><td colspan="2">C</td><td colspan="4">D</td><td colspan="2">E</td></tr>
<tr><td>18</td><td>D</td><td colspan="7">E</td></tr>
</table>

Ship H

<table>
<tr><th>Year / Speed</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>13</td><td colspan="8">A</td></tr>
<tr><td>14</td><td colspan="5">A</td><td colspan="3">B</td></tr>
<tr><td>15</td><td>A</td><td colspan="4">B</td><td colspan="3">C</td></tr>
<tr><td>16</td><td colspan="2">B</td><td colspan="4">C</td><td colspan="2">D</td></tr>
<tr><td>17</td><td colspan="2">C</td><td colspan="4">D</td><td colspan="2">E</td></tr>
<tr><td>18</td><td colspan="2">D</td><td colspan="6">E</td></tr>
</table>

Fig. 2 CII ratings of containerships by ship speed

Table 2 presents the annual average speed of each ship to keep the 'C' level. Although the details differ by ships, compliance with the CII regulation requires the speed reduction of 0.2~0.4 knots every year, resulting in slow steaming by 2 knots for the period 2023-2030.

Table 2 Average ship speed in compliance with CII

(Unit: knots)

	2023	2024	2025	2026	2027	2028	2029	2030
A	17.6	17.4	17.2	16.9	16.5	16.2	15.8	15.3
B	16.1	15.9	15.6	15.4	15.1	14.7	14.4	14.0
C	16.1	15.8	15.6	15.4	15.0	14.6	14.2	13.9
D	16.3	16.1	15.8	15.6	15.2	14.9	14.5	14.1
E	18.4	18.3	18.1	17.9	17.6	17.2	16.9	16.5
F	18.1	17.9	17.7	17.5	17.1	16.8	16.4	16.0
G	17.4	17.2	17.0	16.8	16.5	16.2	15.9	15.5
H	17.5	17.3	17.1	16.9	16.6	16.2	15.9	15.5

Furthermore, this study calculates the losses of working days resulting from slow steaming in order to keep the 'C' level. Following the results presented in Table 2, this study analyzes the working days at the speed of CII compliance. Since the average speed for CII compliance is 17.2 knots and minimum value is 16.1 (for ships B and C) this study compares the results with the working days at 16 knots and 17 knots. Table 3 and Table 4 shows the differences in working days at different speeds, respectively.

As seen in Table 3, the results indicate that older containerships will experience the losses of working days when they keep the ship speed complying with the CII regulations, compared to the assumption of sailing speed of 16 knots. Especially, in case of Ship B and Ship C, the losses of working days will occur from 2024. In stark contrast, younger ships will undergo either no losses (Ship E) or losses in later years in 2029 and 2030.

Table 3 Difference in working days at speed of CII compliance and 16 knots

(Unit: days)

Ship	2023	2024	2025	2026	2027	2028	2029	2030
A	+35.2	+30.2	+25.0	+19.6	+11.8	+3.6	-5.1	-14.1
B	+2.0	-2.8	-7.8	-12.9	-20.2	-27.7	-35.5	-43.5
C	+1.7	-3.4	-8.6	-14.0	-21.7	-29.6	-37.8	-46.3
D	+6.9	+1.9	-3.4	-8.8	-16.4	-24.3	-32.6	-41.1
E	+52.8	+48.8	+44.6	+40.1	+33.7	+26.8	+19.5	+11.8
F	+45.8	+41.2	+36.5	+31.5	+24.2	+16.5	+8.4	-0.4
G	+30.1	+25.8	+21.5	+17.0	+10.7	+4.0	-3.0	-10.7
H	+33.1	+28.7	+24.1	+19.3	+12.4	+5.1	-2.4	-10.3

In addition, the results reveal that more serious losses of working days when compared to the ship speed of 17 knots. In cases of older vessels, the losses of working days occur through all the years in the sample (Ship B, C and D). Even younger vessels will also experience working day losses in the earlier years of 2025 (Ship G).

Table 4 Difference in working days at speed of CII compliance and 17 knots

(Unit: days)

Ship	2023	2024	2025	2026	2027	2028	2029	2030
A	+13.6	+8.6	+3.4	-2.0	-9.8	-18.0	-26.7	-35.7
B	-19.6	-24.4	-29.4	-34.5	-41.8	-49.3	-57.1	-65.1
C	-19.9	-25.0	-30.2	-35.6	-43.3	-51.2	-59.4	-67.9
D	-14.7	-19.7	-25.0	-30.4	-38.0	-45.9	-54.2	-62.7
E	+31.2	+27.2	+23.0	+18.5	+12.1	+5.2	-2.1	-9.8
F	+24.2	+19.6	+14.9	+9.9	+2.6	-5.1	-13.2	-21.7
G	+8.4	+4.2	-0.1	-4.6	-10.9	-17.6	-24.6	-31.8
H	+11.5	+7.1	+2.5	-2.3	-9.2	-16.5	-24.0	-31.9

Finally, Table 5 shows the share of working days resulting from speed reduction for CII ratings. It is obvious that older ships will experience two-digit percent of working days loss.

Table 5 Share of working days loss

Ship	Speed	2023	2024	2025	2026	2027	2028	2029	2030
A	16							-1.4%	-3.9%
	17				-0.6%	-2.7%	-4.9%	-7.3%	-9.8%
B	16		-0.8%	-2.1%	-3.5%	-5.5%	-7.6%	-9.7%	-11.9%
	17	-5.4%	-6.7%	-8.1%	-9.5%	-11.5%	-13.5%	-15.6%	-17.8%
C	16		-0.9%	-2.4%	-3.8%	-5.9%	-8.1%	-10.4%	-12.7%
	17	-5.4%	-6.8%	-8.3%	-9.8%	-11.9%	-14.0%	-16.3%	-18.6%
D	16			-0.9%	-2.4%	-4.5%	-6.7%	-8.9%	-11.3%
	17	-4.0%	-5.4%	-6.8%	-8.3%	-10.4%	-12.6%	-14.8%	-17.2%
E	16								
	17							-0.6%	-2.7%
F	16								-0.03%
	17						-1.4%	-3.6%	-5.9%
G	16							-0.8%	-2.8%
	17			-0.1%	-1.2%	-3.0%	-4.8%	-6.7%	-8.7%
H	16							-0.7%	-2.8%
	17				-0.6%	-2.5%	-4.5%	-6.6%	-8.7%

5. Conclusion

This paper investigates the impact of slow steaming on containership operations under the CII regulation. To this end, eight containerships with various ages and sizes are examined in terms of the degree of speed reduction in compliance with the CII regulation and the losses of working days.

The findings in this study can be summarized into three points. First, without slow steaming, containerships will undergo degradation of the CII rating on the business-as-usual condition. Second, in order to maintain the minimum CII rating, the speed reduction of roughly 0.2 or 0.4 knots is required every year, resulting in total 2 knots of reduction for the period 2023-2030. Finally, the speed reduction in compliance with the CII ratings leads to significant losses of working days for containerships as many as 6 or 7 days every year.

The findings in this study offer some important implications for business operation of container shipping companies. First, slow steaming can be an effective measure to environment regulations in the short term. This is especially true for younger ships, but not for older ships. Second, in the long term, container shippinc companies should make efforts to combine slow steaming and other measures (e.g. alternative fuels and energy efficiency) for compliance with environment regulations.

Despite the valuable findings that this study offers, ther are some limitations calling for further research in the future. First, this study deals with only the container shipping sector. As the vessel and operational characteristics vary by ship types, a more comprehensive research can provide a valuable findings regarding the impact of slow steaming on shipping operations. Second, this study relies on the assumption of the annual average speed. Since ships, in general, sail at different speeds according to locations, the fuel consumption also varies. However, this point is not considered in this study. Finally, future research should consider the measures to compensate the losses of working days resulting from slow steaming.

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References

[1] Adland, R., Cariou, P. and Wolff, F. C.(2020), "Optimal Ship Speed and the Cubic Law Revisited: Empirical Evidence from an Oil Tanker Fleet", Transportation Research Part E: Logistics and Transportation Review, Vol. 140, p. 101972.

[2] Anh, D. P., Rim, R. B. and Kang, H.(2023), "Design and Analysis of a Novel Methanol SOFC Combined System for Marine Applications Toward Future Green Shipping Goals", Journal of Navigation and Port Research, Vol. 47, No. 2, pp. 106-119.

[3] Buhaug, Ø., Corbett, J. J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D. S., Lee, D., Lindstad, H., Markowska, A. Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J. J., Wu, W. and Yoshida, K.(2009), Second IMO Greenhouse Gas Study 2009, International Maritime Organization.

[4] Cariou, P.(2011), "Is Slow Steaming a Sustainable Means of Reducing CO2 Emissions from Container Shipping?", Transportation Research Part D: Transport and Environment, Vol. 16, No. 3, pp. 260-264.

[5] Chapman, J. D.(1989), Geography and Energy: Commercial Energy Systems and National Policies, Longman Scientific & Technical, New York.

[6] Degiuli, N., Martic, I., Farkas, A. and Gospic, I.(2021), "The Impact of Slow Steaming on Reducing CO2 emissions in the Mediterranean Sea", Energy Reports, Vol. 7, pp. 8131-8141.

[7] Eide, M. S., Chryssakis, C. and Endresen, O.(2013), "CO2 abatement potential towards 2050 for shipping including alternative fuels", Carbon Management, Vol. 4, No. 3, pp. 275-289.

[8] Farkas, A., Degiuli, N., Martic, I. and Mikulic, A.(2023), "Benefits of Slow Steaming in Realistic Sailing Conditions along Different Sailing Routes", Ocean Engineering, Vol. 275, p. 114143.

[9] Farkas, A., Degiuli, N., Martic, I. and Vujanovic, M.(2021), "Greenhouse Gas Emissions Reduction Potential by Using Antifouling Coatings in a Maritime Transport Industry", Journal of Cleaner Production, Vol. 295, p. 126428.

[10] Ferrari, C., Parola, F. and Tei, A.(2015), "Determinants of Slow Steaming and Implications on Service Patterns", Maritime Policy and Management, Vol. 42, No. 7, pp. 636-652.

[11] IMO(2018), Resolution MEPC.304(72), the Marine Environment Protection Committee.

[12] IMO(2021a), Resolution MEPC.328(76), the Marine Environment Protection Committee.

[13] IMO(2021b), Resolution MEPC.338(76), the Marine

Environment Protection Committee.
[14] IMO(2022a), Resolution MEPC.353(78), the Marine Environment Protection Committee.
[15] IMO(2022b), Resolution MEPC.354(78), the Marine Environment Protection Committee.
[16] Kim, Y. R., Kim, G. and Park, J. B.(2019), "A Study on the Prediction of Fuel Consumption of a Ship Using the Principal Component Analysis", Journal of Navigation and Port Research, Vol. 43, No. 6, pp. 335-343.
[17] Lindstad, H., Asbjornslett, B. E. and Stromman, A. H.(2011), "Reductions in Greenhouse Gas Emissions and Cost by Shipping at Lower Speeds", Energy Policy, Vol. 39, No. 6, pp. 3456-3464.
[18] Maloni, M., Paul, J. A. and Gligor, D. M.(2013), "Slow Steaming Impacts on Ocean Carriers and Shippers", Maritime Economics and Logistics, Vol. 15, No. 2, pp. 151-171.
[19] Mander, S.(2017), "Slow Steaming and a New Dawn for Wind Propulsion: A Multi-level Analysis of Two Low Carbon Shipping Transitions", Marine Policy, Vol. 75, pp. 210-216.
[20] Smith, T. W. P., Jalkanen, J. P., Anderson, B. A., Corbett, J. J., Faber, J., Hanayama, S., O'keeffe, E., Parker, S., Johansson, L. and Aldous, L.(2015), Third IMO Greenhouse Gas Study 2014, International Maritime Organization.
[21] Tran, N. K. and Lam, J. S. L.(2022), "Effects of Container Ship Speed on CO2 Emission, Cargo Lead Time and Supply Chain Costs", Research in Transportation Business and Management, Vol. 43, pp. 100723.
[22] Wong, E. Y., Thai, A. H., Lau, H. Y. and Raman, M.(2015), "A Utility-based Decision Support Sustainability Model in Slow Steaming Maritime Operations", Transportation Research Part E: Logistics and Transportation Review, Vol. 78, pp. 57-69.
[23] Yang, H. N., Lee, G. U. and Shin, C. H.(2019), "A Study on the Priority Analysis of Government Support Policies for SOx Emission of Ships", Journal of Navigation and Port Research, Vol. 78, No. 2, pp. 86-92.
[24] Yuan, Q., Wang, S. and Peng, J.(2023), "Operational Efficiency Optimization Method for Ship Fleet to Comply with the Carbon Intensity Indicator (CII) Regulation", Ocean Engineering, Vol. 286, p. 115487.

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