# Tracking Carbon Intensity of Global Container Fleet: Carbon Emissions Index (CEI)

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With increasing pressure on the environment and the adoption of regulatory frameworks and policies aimed at reducing the carbon footprint of shipping, data-driven solutions are increasingly being deployed. This is particularly relevant for container shipping as it has inherently fixed liner services that correlate with the dominance of fuel costs in the overall cost structure, but also with the trends of overall capacity expansion and severe exogenous influences that contribute to supply chain disruptions. This paper presents the methodological background of the Carbon Emissions Index (CEI), a tool to measure the $CO_2$ emissions of global container shipping companies and to validate the dynamics of change between available container trade routes. A comprehensive systematic analysis of the metrics and operational variables used in the algorithm is presented, as well as an overview of the practical application of CEI intensity and dynamics using the selected container trade routes. The results of this research highlight the role of digitalization in measuring the carbon footprint of container companies and the importance of reporting environmental performance through indices in shipping as an integral part of the contingent of performance metrics.

**KEY WORDS**

~ CEI
~ Container shipping
~ Carbon footprint
~ Environmental pollution
~ Digitalization

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doi: 10.7225/toms.v13.n01.022

Received: 27 Feb 2024 / Revised: 10 Apr 2024 / Accepted: 15 Apr 2024 / Published: 20 Apr 2024

# 1. INTRODUCTION

The impact of climate change, described as one of the largest cascading crises on a global scale, has accelerated the decarbonization of the shipping industry, which is responsible for almost 3% of global greenhouse gas emissions (UNCTAD, 2023). This coincides with the adoption of regulatory frameworks and policies at global, European and institutional levels aimed at significantly reducing air emissions, creating a zero-emission environment and combating climate change. One of the most influential policies at different geographical levels is the Paris Agreement, which sets ambitious targets to limit the temperature increase to 1.5°C above pre-industrial levels (UNFCCC, 2015), the "Fit for 55" package of the European Union (EU) climate target to reduce emissions by at least 55% by 2030 and the measures to achieve climate neutrality in the EU by 2050 (EC, 2021) and the revised strategy to reduce greenhouse gas emissions from ships adopted by the International Maritime Organization (IMO) in 2023, which sets a target of net-zero GHG emissions by around 2050, in addition to phasing out carbon emissions over the years (IMO, 2023). Shipping is at the heart of the debate on decarbonization and climate change, particularly with regard to the lack of correlation between the increasing demand for ships and the necessary but rather time-consuming improvements in fuel efficiency (UNCTAD, 2023), a relationship that is now to be overcome by applying slow steaming-practices (Notteboom *et al*., 2023). This is particularly true for container shipping as the increase in ship size, various exogenous influences (geopolitics, climate change, etc.), and the high share of fuel costs in the overall cost structure (Stopford, 2009) have a negative impact on fixed liner services. Container shipping is the nucleus of maritime trade, particularly in terms of the total value of goods transported. Around two-thirds of the total value of 70% of international maritime trade is transported in containers (UNCTAD, 2021). Trade in containers primarily involves finished and semi-finished products, and goods with high unit prices where container services and networks are complex, as opposed to commodities. Although container shipping is essential for international trade, it is also a significant contributor to overall air emissions, particularly carbon dioxide ($CO_2$) emissions from fuel combustion, but also other emissions of air pollutants such as sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$) and particulate matter (PM). On this basis, the IMO adopted mandatory changes for all ships in the active fleet in early 2023, requiring the calculation of achieved energy efficiency through the Energy Efficiency Existing Ship Index (EEXI), the definition of steps to improve the ship's energy efficiency through the improvement of the Ship Energy Efficiency Management Plan (SEEMP) and reporting on the annual operational Carbon Intensity Indicator (CII) and CII ratings (DNV, 2023). This was a continuation of the IMO's goal to reduce carbon emissions in the short term and achieve the long-term goal of completely eliminating shipping's carbon footprint. The IMO already set emission standards for marine diesel engines in 2008 to combat harmful NOx emissions and limited the total sulfur content in fuel oil to 0.5% in 2020 under the International Convention for the Prevention of Pollution from Ships (MARPOL Convention) (IMO, 2021). With the adoption of the 2020 sulfur cap, the IMO has encouraged the use of compliant fuels such as Very Low Sulfur Fuel Oil (VLSFO) and Marine Gas Oil (MGO) while leaving open the alternative of using scrubbers that allow the continued use of Heavy Fuel Oil (HFO). The HFO is the predominant fuel type in shipping and accounts for about 80% of the total fuel consumption of the world fleet (Zhang et al., 2021) as bunker prices are low compared to other distillates but cause higher emissions. It is assumed that the HFO with scrubbers is the most economical solution for container ships in the short term (Zou and Yang, 2023). To counteract rising greenhouse gas emissions, the global shipping industry is currently undergoing a transformation in fuel technology and the energy industry, with a trend towards using carbon-neutral fuels to achieve a zero-emission industry (DNV, 2022), even if the current state of technology is still below the targets set.

Considering the increasing decarbonization initiatives in shipping and the sustainability awareness that has already become part of shippers' decision-making when selecting carriers for the transport of goods, there is a need to increase the use of data-driven solutions and the level of information between all parties involved in container transport by sea based on the environmental impact of container shipping. In order to track the $CO_2$ emissions of global container shipping and validate the dynamics of changes between the available container trade lanes, this article looks at the analysis of the Carbon Emissions Index (CEI), a tool that has been introduced as the optimal solution for monitoring carbon emissions. Unlike the other available indices in the shipping industry, which mainly focus on the information of efficiency of the freight market as an indicator of price movements (Adland *et al*., 2017), the CEI calculates the environmental performance of individual container carriers by aggregating multiple operational variables and vessel data from the carrier's actual voyage, providing a reliable and sustainable solution for tackling carbon emissions (Xeneta, 2022). The objectives set in this paper aim to segment and elaborate the CEI metrics and variables used in the platform, along with an overview of the practical application of CEI intensity and dynamics based on the selected container trade lines. The findings of this research aim to highlight the role of digitalization in measuring the carbon footprint of container companies and the importance of reporting environmental performance through indices in shipping as an integral part of the contingent of performance metrics.

## 2. CEI METHODOLOGY

As mentioned above, the aim of the CEI is to assess the environmental performance of container ships by combining real-time data from the Automatic Identification System (AIS) transponders and ship specifications. The combination of the two data sets enables the calculation of $CO_2$ emissions per ton of cargo carried by individual liner ships as well as the comparison of carbon emissions with the average of trade routes. The visualization of the metrics used in the CEI algorithm is shown in Figure 1.

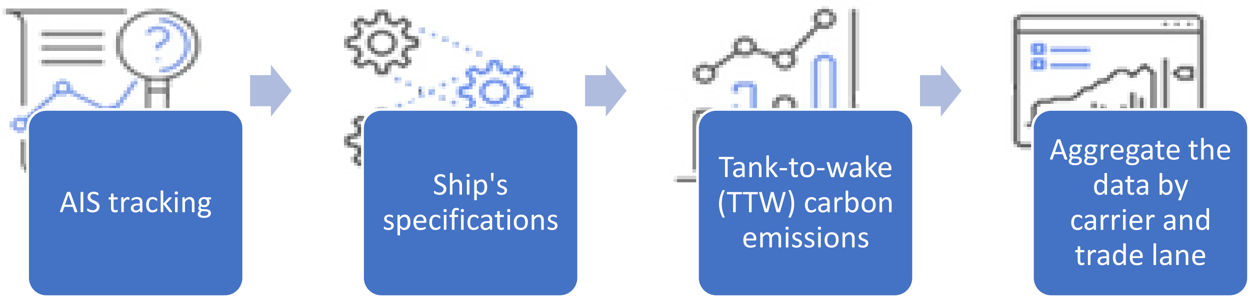


Figure 1. Metrics in Carbon Emissions Indicator algorithm (Source: Xeneta, 2022)

The CEI is only applied to container shipping companies and the 13 most important global trade lanes. The algorithm's metrics include data on actual speed, cargo, voyage time and congestion, the latter focusing mainly on time spent at anchor, location and draught (Xeneta, 2022). This data comes primarily from the ship's AIS system, which was originally designed for radar augmentation and vessel traffic service (VTS). However, as the voyage-related data and AIS messages are increasingly used in research (Svanberg *et al*., 2019), the AIS data are often used for the calculation of traffic indicators in the observed area (Aarsæther and Moan, 2009). In the second phase, the AIS data is merged with the engine type and consumption data from the ship specifications. Based on the combination of these two parameters, the carbon emissions of the individual vessels are calculated. It should be emphasized that the calculated total emissions represent only the tank-to-wake (TTW) emissions, including the total $CO_2$ emitted as a product of fuel combustion on board, while the emissions generated in the previous stages of the emission life cycle, such as resource extraction or fuel production, processing, transportation and distribution, referred to as well-to-tank (WTT) emissions, are not considered (Istrate *et al*., 2022). The final stage of data processing within the CEI algorithm is the aggregation of the calculated carbon footprint of individual container carriers and trade lines (Xeneta, 2022). As one of the CEI's objectives is to analyze the dynamics and structure of changing trends over time, all quarterly calculated data is compared with the average values for trade routes and carriers indexed to the baseline values of the first quarter of 2018. The list of variables included in the two baseline datasets for the calculation of total carbon emissions is shown in Figure 2.

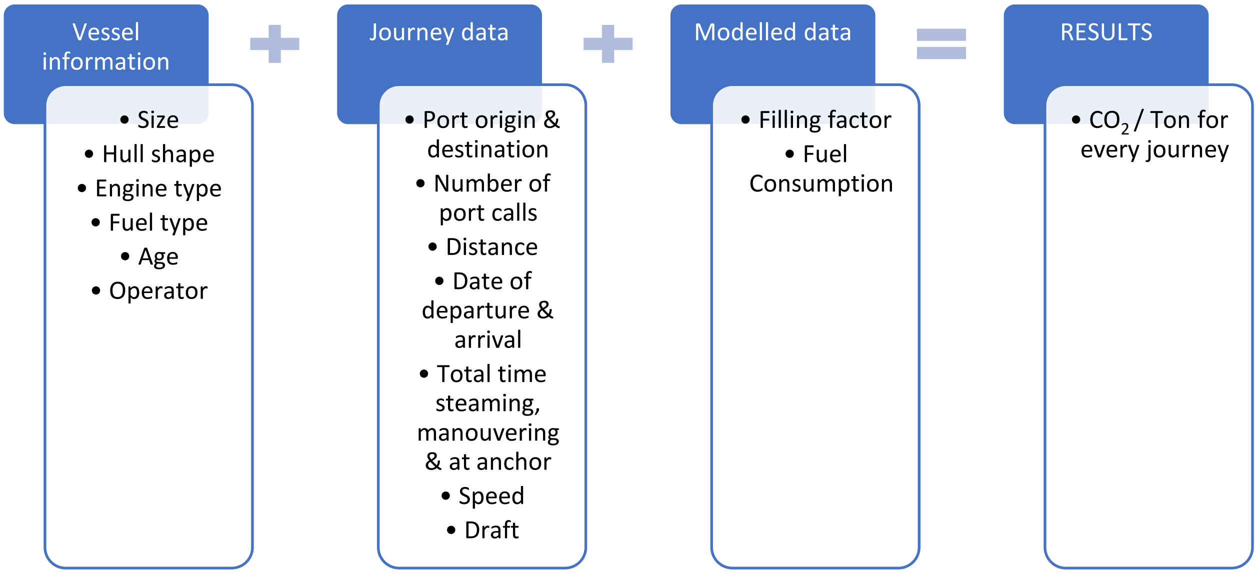


Figure 2. Variables used for the carbon emissions calculation (Source: Xeneta, 2022)

Finally, to create a $CO_2$ emissions index, the carbon footprint of each trip is compared with the selected trade route. When determining exceptional values, the data for each container carrier and trade route is modeled on a quarterly basis and compared to the baseline (2018 = index of 100) (Figure 3.).

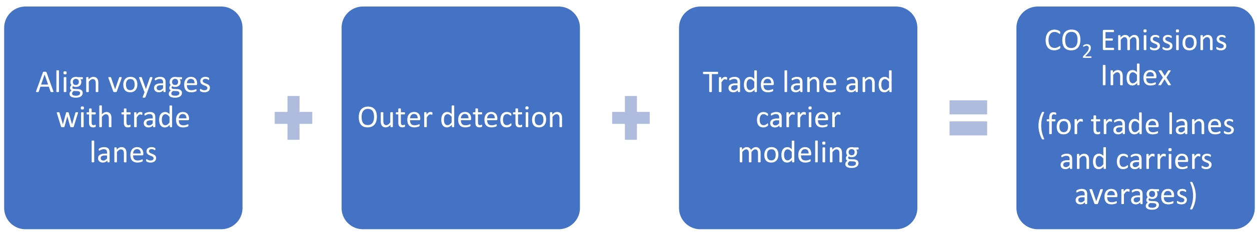


Figure 3. CEI calculation for individual carrier and trade line considered (Source: Xeneta, 2022)

## 3. PRACTICAL APPLICATION OF CARBON EMISSIONS INDEX BASED ON PERFORMANCE OF CARRIERS AND TRADE ROUTES

### 3.1. Operational variables shaping the CEI

To develop an algorithm that generates results comparable to the average performance of container companies and trade routes, the CEI metadata is based on four interrelated variables. These operational variables are combined in the model to produce quarterly reports that show the change in intensity and dynamics of each parameter, reflecting the change in the overall environmental performance of the area under study, but also the changing trends as a result of various natural and anthropogenic influences. The defined variables include the filling factor, the sailing speed, the age of the vessels and the vessel size (Figure 4.).

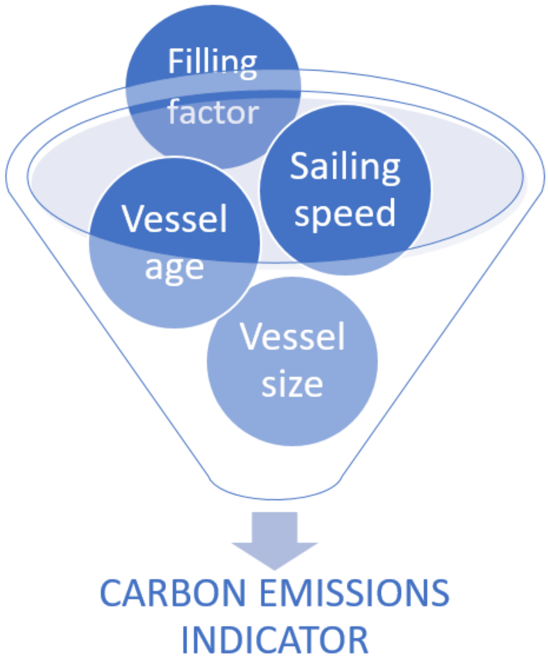


Figure 4. Four CEI pillars in reporting on environmental performance of carriers and trade lines

The filling factor refers to the capacity utilization of the ship, i.e., the total carrying capacity of the ship occupied by paying freight (Alizadeh and Talley, 2011). This measure applies to all shipping segments, while the measurement of cargo capacity is determined by ship type, with TEU referring to container ships. In addition, the intake of containers is usually limited by volume; so, capacity utilization refers to the proportion of the total volume available for loading (Adland *et al*., 2018). In contrast, the sailing speed of container ships is closely linked to the liner service in terms of arrival time between neighboring ports. The sailing speed of a ship not only has a significant impact on the total cost of ownership, but also correlates with bunker consumption, making it very sensitive to adjustments (Wang and Meng, 2012). When ships travel at high speed, they emit a higher amount of air emissions per ton-kilometer compared to the conditions where the speed is reduced below the design speed, i.e., slow steaming (Psaraftis *et al*., 2009). The concept of slow steaming is primarily a commercial decision that leads to a reduction in fuel consumption, while it is also becoming an indicator of the environmental performance of ships in the era of increasing environmental challenges that affect also the shipping industry in particular (Mohammed, 2023). In general, the dynamics of global fleet renewal and recycling are fundamentally dependent on the age profile of the global fleet, which is a key factor for compliance with increasing environmental regulations and following variables in the CEI metrics. The average age of all merchant ships was 22.2 years in early 2023, while the containership fleet was 14.2 years old (UNCTAD, 2023). Ship age correlates with the technical and operational efficiency of general voyages; so, the tendency of container companies is to gradually replace the aging fleet and deploy newer vessels on key routes based on their seniority. In addition, newer ships have better carbon efficiency and, therefore, produce fewer emissions (Li *et al*., 2023). Within the cost structure, the operating and voyage costs of older ships tend to increase compared to newer, more efficient ships, while the capital costs are degressive. Furthermore, for a given spot rate, an older ship generates less money than a new ship, so the use of older ships in trade, especially during the depression, depends primarily on the market balance between supply and demand, and regular maintenance (Stopford, 2009). The final variable that defines the CEI is ship size. The increase in the size of container ships is usually driven by the need to achieve greater economies of scale and, thus, reduce transportation costs for container trading hubs

(Malchow, 2017). In general, the maximum size of container ships has doubled since 2000, with the largest vessels being deployed and operating on the trade routes between the Far East and Northern Europe, due to the complexity of designing a container service that includes multiple hub ports and multiple destination ports with feeder services on this route (Tai and Wang, 2022). The trend towards upscaling ships is related to the increasing operational challenges in both port terminal and hinterland operations, which correlates with the need to expand the overall transportation system that must be available to accommodate the larger ships (Notteboom *et al*., 2022). However, due to the larger transportation capacity, larger vessels have higher total emissions but lower carbon emissions per unit of transport (Tai, 2015). This means that increasing the size of ships is beneficial for reducing emission (Zakaria and Rahman 2017; Zhao *et al.* 2021). The combination of technical improvements and the introduction of new technologies that significantly improve fuel efficiency, and the application of slow steaming practices and other improvements in the environmental performance of specific port community stakeholders' activities can significantly reduce the carbon footprint of the global container fleet (Notteboom *et al*., 2022; Tai and Wang, 2022).

## 3.2. CEI variables dynamics and intensity analysis on selected trade routes

In addition to the dynamics of total carbon dioxide emissions from global carriers and selected trade routes, the operational variables that shape the CEI provide insights into trends and changes in service speed, capacity management, the deployment of new vessels, and the intensity of trade on individual container routes. As mentioned above, the reports are produced quarterly to provide measurable results that consider the dynamics of change in the variables analyzed. The combination of the individual parameters results in the carbon footprint for the individual carriers operating on the selected trade route at a given time. For example, Figure 5 shows the dynamic change in the average speed of the container carrier *Ocean Network Express* (ONE) operating on the Far East - Mediterranean trade lane compared to average of the trade lane in the period Q2 2018 – Q3 2023. In Q3 2023, the shipping company ONE reported the most efficient carbon performance, which included the vessel size of 14,900 TEU, the average ship age of just over three years, the filling factor corresponding to the trade lane and, in particular, the average speed of 15.2 knots, which was below the average of the trade lane (15.5 knots) (Xeneta, 2023a). The combination of younger vessels, optimal ship capacity, lower service speed, and average filling factor resulted in an optimal carbon footprint and trade lane performance for ONE.

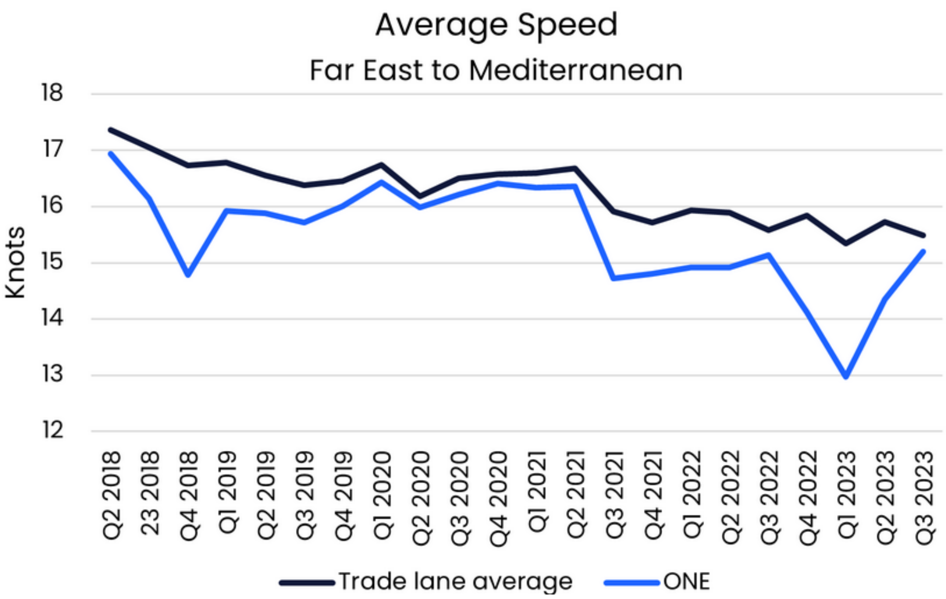


Figure 5. Average ship speed of carrier ONE on route Far East – Mediterranean (Source: Xeneta, 2023a)

As an example, for the analysis of the fill factor in the period Q3 2022 – Q3 2023, backhaul traffic from Northern Europe to the Far East was selected and compared using the selected container carriers and the average values of the trade routes (Figure 6). In general, backhaul trades are problematic for shipping lines as they have to balance the carbon footprint and maintain the profitability of fronthaul trades. For the period Q3 2023, CMA CGM was the most efficient carrier according to the mix of operating variables. Despite the low filling factor (64.7%) and the slightly higher sailing speed of 14.9 knots (increase of 2 knots compared to Q1 2023), the company's carbon performance was optimal due to the average ship age of 5.7 years and the higher size of the vessel deployed on the route of 20,184 TEU (increase of 4%) (Xeneta, 2023b). The average age of CMA CGM's vessels deployed on the routes was the dominant variable causing the prioritization of the shipping line by overall carbon footprint.

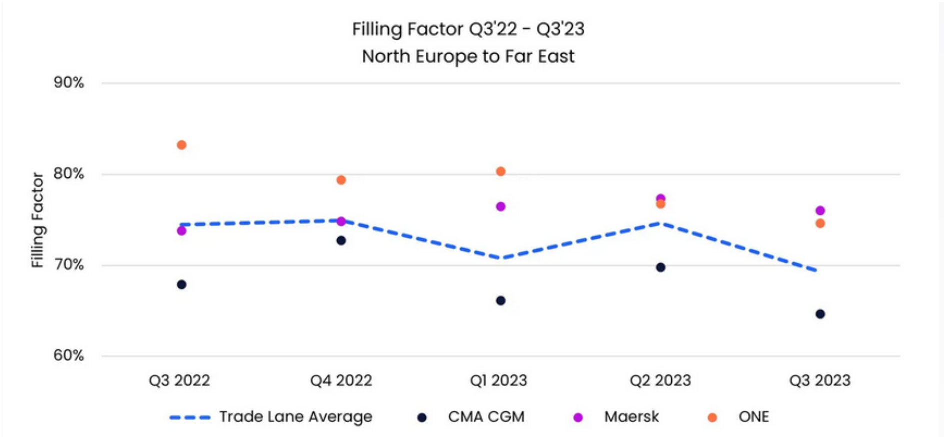


Figure 6. Average filling factors of selected carriers operating on Northern Europe – Far East route (Source: Xeneta, 2023b)

To illustrate the analysis of ship age, the indicators for the results of Q1 and Q2 in 2023 on the Mediterranean – Far East route were compared for all container ships (Figure 7). The most efficient shipping company in terms of overall carbon intensity was shipping company ONE, mainly due to its lower speed of 12.3 knots and average vessel age of 4.2 years, which was 2.5 years below the average age on this route (Xeneta, 2023c). The analysis of the change in the dynamics of the average age between quarters also showed a lower age for most shipping companies on the Mediterranean – Far East route (in 2023), while only four container companies operated ships with an age higher than the lane average.

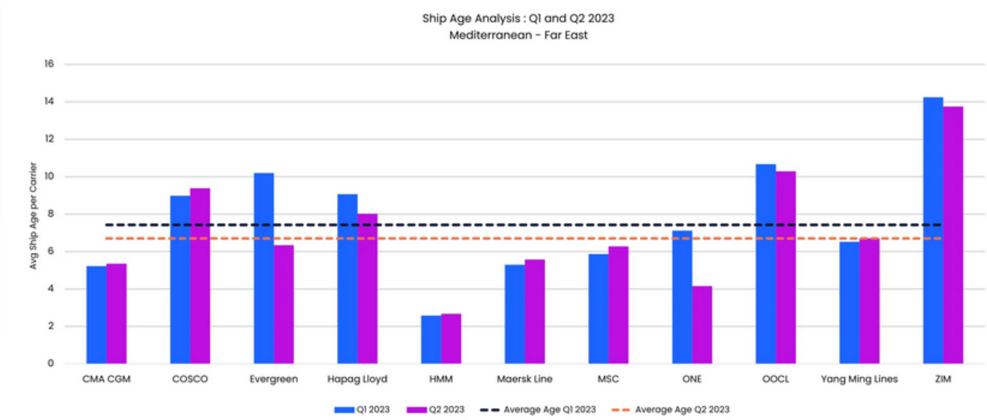


Figure 7. Average ship age of selected carriers operating on Mediterranean – Far East route (Source: Xeneta, 2023c)

Finally, the development of ship size was analyzed using the example of the shipping company Pacific International Lines (PIL) for the Far East – South America East Coast trade, looking at the period Q1 2021 – Q2 2023 (Figure 8). For Q2 2023, PIL was the most environmentally efficient shipping company as it used a slightly reduced speed of 14.7 knots (1.1 knots below the trade lane average), younger vessels (2.5 years less than average) and a higher fill factor (90%) despite operating larger vessels than average on this trade route (Xeneta, 2023d). The nominal ship capacity of the ships deployed on the Far East – South America East Coast route exceeded the 10,000 TEU mark in the first and second quarters of 2023.

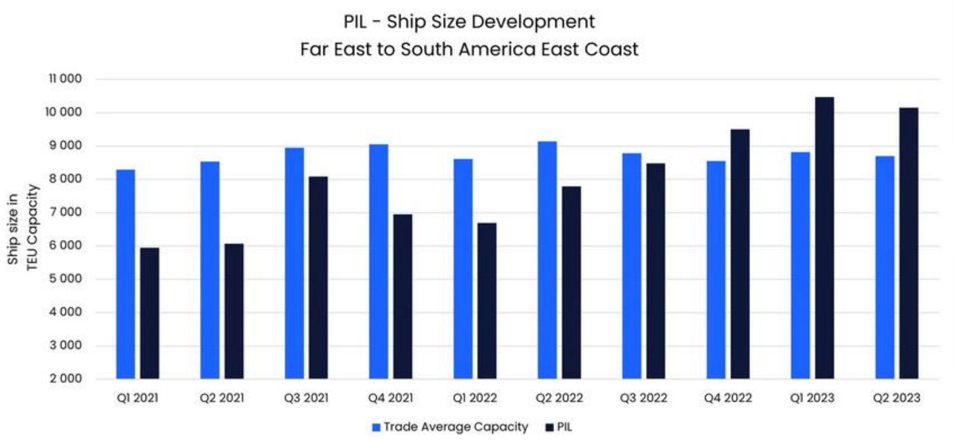


Figure 8. Average ship size of shipping company PIL operating on the Mediterranean – Far East route (Source: Xeneta, 2023d)

## 3.3. Overview of environmental performance of shipping routes based on CEI evaluation

The measurement of carbon intensity, which includes the CEI variables, is applied to selected trade routes based on the individual environmental performance of container companies. These trade routes differ in intensity, dynamics, structure and direction, and are closely linked to market forces and freight rates as a result of the relationship between the two dimensions. Table 1 shows the average values of the variables shaping the CEI for Q3 2023, which are used to determine the final $CO_2$ emissions of the analyzed shipping route.

| TRADE LANE | AVERAGE CAPACITY | AVERAGE AGE | AVERAGE SPEED | AVERAGE FILLING FACTOR |
|---|---|---|---|---|
| Far East – Mediterranean | 14,900 TEU | n/a | 15.5knots | n/a |
| Far East – North Europe | 19,000 TEU | 6.6 years | n/a | n/a |
| Far East – South America East Coast | n/a | 10 years | n/a | 92.8 % |
| Far East – US West Coast | 9,545 TEU | 10.6 years | n/a | 81.3 % |
| North Europe – Far East | n/a | 6.6 years | n/a | 69.3 % |
| North Europe – US East Coast | 7,340 TEU | 13.7 years | n/a | 57.9 % |
| US East Coast – North Europe | 11,888 TEU | n/a | n/a | 37 % |
| US West Coast – Far East | 9,281 TEU | n/a | 15.2 knots | 56.5 % |

Table 1. Average value of variables used to determine carbon intensity on selected shipping routes for Q3 in 2023 (Source: Xeneta, 2023a-d)

In addition to being able to quantify the dynamics of the carbon footprint of shipping companies operating on different shipping routes, the analysis of individual operational variables reflects the trends in global shipping, but also in the global economy. For example, based on the data from Table 1 for the third quarter of 2023, the average capacity of vessels on fronthaul and backhaul voyages (e.g., North Europe – US East Coast) differs from the average size of vessels deployed in relation to the average fill factor. However, when analyzing the data generated, the macroeconomic framework conditions should be considered, in particular the trends and characteristics of the market. In this case, the low fill factor can be justified by the overcapacity, the influx of new ships ordered in 2022, and the prioritization of profitability of other routes at the expense of transatlantic fronthaul and backhaul routes.

Finally, Figure 9 shows examples of the application of the CEI according to each carrier's performance for the fronthaul and backhaul routes from the Far East to Northern Europe in the period Q2 2018 – Q4 2022. Based on their carbon intensity, carriers are ranked quarterly in relation to the average of the trade routes and the baseline scenario (index 100). These results allow shippers to be fully informed about the sustainability awareness of shipping companies in the face of increasing environmental challenges in the shipping industry, but also about their operational performance in terms of current and future policy measures to be applied.

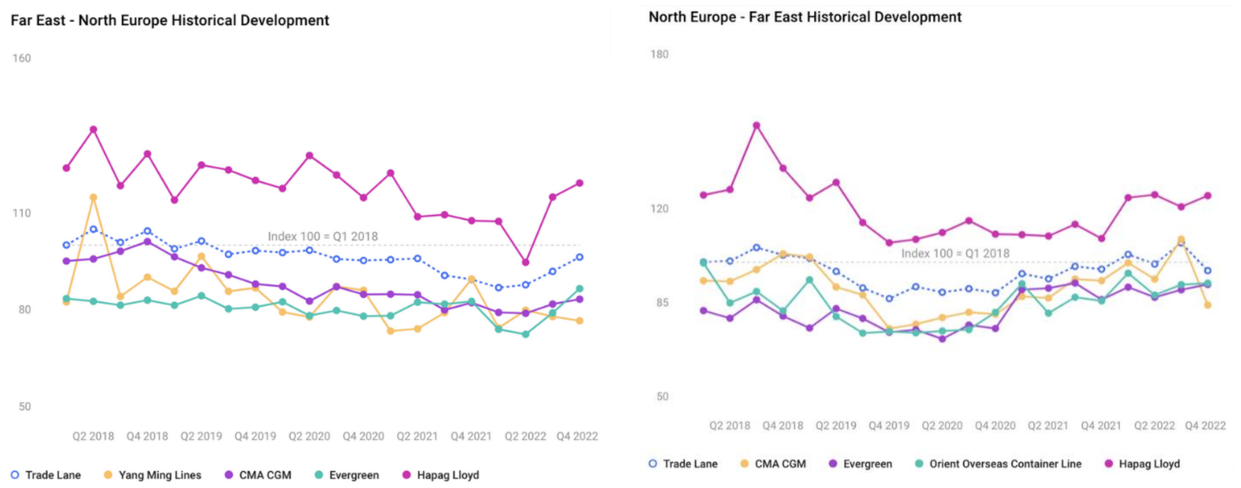


Figure 9. CEI applied to Far East - North Europe fronthaul and backhaul routes (Source: Xeneta, 2023e; Xeneta, 2023f)

## 4. DISCUSSION AND CONCLUSION

Sustainability indicators are becoming a competitive factor for environmental, social and governance (ESG) programs that define a set of standards and establish priorities and actions to be aligned with sustainable, long-term values (OECD, 2020). Increasing environmental pressures in the shipping industry have highlighted the need for effective mechanisms to monitor the carbon intensity of individual transportation companies operating on the selected shipping route. By utilizing the available databases from relevant sources while avoiding the subjective perception of container companies to achieve more accurate and independent results, the carbon emissions index has evolved from a traditional unit of measurement to a decision-making tool. This mainly concerns shippers to assess the level of sustainability awareness of the transportation company in terms of applying measures to reduce the carbon footprint of their operations. The combination of the operational variables extracted from AIS data and the data on ship specifics determines the ranking of container companies and trade lanes according to a certain level of carbon performance generated. The CEI is not only an important decision-making tool for shippers, but also reflects the state of the shipping industry and provides insights into recent changes in the global economic trends. This assertion can be justified by the interconnectedness of global shipping and the redeployment of ships. For example, in the third quarter of 2023, in response to subdued global demand, shipping companies opted to shift excess tonnage of newly-built vessels to the North Europe to US East Coast route instead of decommissioning surplus vessels. This business decision led to an attempt to reduce supply and protect profitability on other trade routes, such as from the Far East to the US West Coast (Xeneta, 2023g). However, due to the lack of demand, this constellation certainly had an impact on carrier fill rates in the North Europe - US East Coast trade lane so that freight rates correlated with capacity utilization (Figure 10).

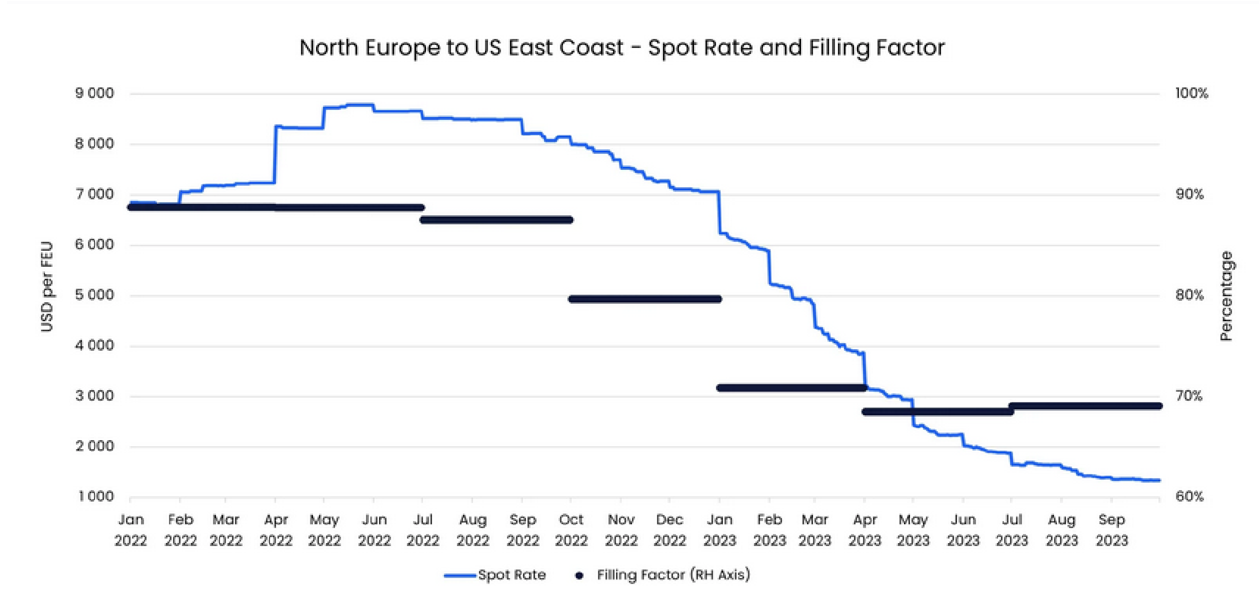


Figure 10. Correlation between filling factor and spot rate in Northern Europe - US East Coast trade lane in Q3 2023 (Source: Xeneta, 2023g)

It should also be emphasized that the lack of capacity utilization, which leads to unnecessary tonnage being added on certain shipping routes, not only affects freight rates, but also the overall carbon emissions of individual container companies, based on average $CO_2$ emissions per ton transported. It is also worth noting that during periods of high demand, cumulative emission levels can increase while at the same time average $CO_2$ emissions per transported ton of cargo decrease. For these reasons, the freight rate for return transportation on the transatlantic route (US East Coast to Northern Europe) reached USD 530 per FEU in December 2023, the rate last reported in 2020 (Xeneta, 2023h).

When analyzing the contribution of CEI operational variables to the general overview of market trends, it can be concluded that the results of slow steaming provide emission benefits, while capacity management on certain shipping routes is fundamental to ensure capacity utilization and is highly dependent on the demand factor. Ship speed is also a variable parameter as it is closely related to market conditions, but it also determines the need to deploy additional vessels on a particular route. The latter can be illustrated by the impact of overcapacity, where shipping companies increase capacity for several services and reduce the speed of the vessels deployed. By reducing the speed, the use of additional vessels for the capacity actually offered can be avoided. The use of smaller vessels than the average for each trade can also have a significant impact on the environmental performance of the shipping company in the different trades. As already indicated, environmental sustainability is the central point in the decision-making process for shippers. Therefore, addressing the carbon footprint of their logistics chains should relate to the optimal distribution of volume across individual trades. From the shippers' perspective, capacity management plays a decisive role in influencing both freight rates and $CO_2$ emissions.

The CEI is an important indicator of the sustainability of shipping operations, especially as it enables real-time quantitative data on carbon intensity. The CEI is not only a decision-making mechanism for the shipping industry, but it can also be used as a supporting tool for the calculation of the European Union Emissions Trading Scheme (EU ETS) and as a useful indicator for determining the Carbon Intensity Indicator (CII) established by the IMO.

## CONFLICT OF INTEREST

The author declares no conflict of interest in the research reported in this paper.

## ACKNOWLEDGEMENTS

This paper was funded under the project line ZIP UNIRI of the University of Rijeka, for the project UIRI – ZIP – 2103-1-22.

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