University of Antwerp

Faculty of Business and Economics

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Navigating the Green Transition: Shipowners' Investment Strategies and Market Interdependencies in Container Liner Shipping amid Decarbonisation Pressures

Thesis submitted for the degree of Doctor of Applied Economics at the University of Antwerp to be defended by Dimitrios Georgoudakis

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Abbreviations

Abbreviation	Definition
ADF	Augmented Dickey-Fuller (test)
AIC	Akaike Information Criterion
ARCH	Autoregressive Conditional Heteroscedasticity
BIC / SBIC	Bayesian Information Criterion / Schwarz Bayesian Information Criterion
CAP	Corrective Action Plan
CAPEX	Capital Expenditures
CBAM	Carbon Border Adjustment Mechanism
CCFI	China Containerised Freight Index
CGT	Compensated Gross Tonnage
CH_4	Methane
CII	Carbon Intensity Indicator
CO_2	Carbon Dioxide
COP26	26th UN Climate Change Conference of the Parties
COVID-19	Coronavirus Disease 2019
CRn / CR4 / CR10	Concentration Ratios (top n, 4, or 10 firms)
DWT	Deadweight Tonnage
EEDI	Energy Efficiency Design Index
EEDIatt	Attained Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
ESG	Environmental, Social, and Governance
ETS / EU ETS	European Union Emissions Trading System
EU	European Union
FE	Fixed Effects
FuelEU	FuelEU Maritime Regulation
GHG	Greenhouse Gas emissions
GT	Gross Tonnage
HFO	Heavy Fuel Oil

HQ	Hannan–Quinn Information Criterion
IMO	International Maritime Organisation
IMO 2020	IMO global sulfur cap regulation (effective January 2020)
IRA	Inflation Reduction Act (U.S.)
LCA	Life Cycle Assessment
LNG	Liquefied Natural Gas
MA	Moving Average
MARPOL	International Convention for the Prevention of Pollution from Ships
MCR	Maximum Continuous Rating of the main engine
MEPC	Marine Environment Protection Committee
MEPC 83	83rd Session of the MEPC
Mt	Million tonnes
NE	Number Equivalent (market concentration index)
NO_x	Nitrogen Oxides
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PAE	power of auxiliary engines
Pb	power of the main engines
P/E ratio	Price-to-Earnings ratio
SCFI	Shanghai Containerised Freight Index
SEEMP	Ship Energy Efficiency Management Plan
S&P	Sales and Purchase (second-hand shipping market)
SO_x	Sulphur Oxides
TEU	Twenty-foot Equivalent Unit
UNCTAD	United Nations Conference on Trade and Development
VECM	Vector Error Correction Model
VLSFO	Very Low Sulphur Fuel Oil

Abstract

The container liner shipping industry plays an important role in global trade, yet faces growing pressure to reduce GHG emissions under IMO and EU decarbonisation measures. To this extent, containerships consistently exhibited the highest share of CO_2 emissions in the maritime sector, ranging from 25.4% to 26.7% between 2019 and the third quarter of 2023, placing them among the top contributors to GHG emissions in international shipping (*OECD,2023*). As the largest emitter within the shipping sector, container shipping is under scrutiny and faces increasing pressures to meet decarbonisation targets. This has created new challenges for shipowners, who must make complex investment decisions under volatile market conditions and regulatory uncertainty.

Given that shipowners are the principal stakeholders investing in the container liner shipping industry, this doctoral dissertation focuses on strategic "green investment" decisions across three interrelated markets: the newbuilding market, the sales and purchase (S&P) market, and the freight (time-charter) market. By integrating regulatory targets, market forces, and technological advancements, the doctoral dissertation seeks to analyse the interdependencies between these markets and to assess how investment strategies can be shaped under decarbonisation pressures. To this extent, the demolition market was deliberately excluded to provide a deeper, more focused analysis of the aspects that directly influence growth opportunities, market expansion, and the strategic decision-making process of investors and shipping companies. The research question that guides this study is:

"In the context of decarbonisation pressures, how do market dynamics, fuel efficiency, and alternative fuels affect asset values and investment decisions in the container liner shipping industry?"

To answer this main research question, the dissertation decomposes the analysis into four sub-questions:

(1) "Which market trends and developments have been observed in the container liner shipping industry?"
(2) "What is the price premium for more fuel-efficient vessels in the time charter market?
(3) "Which are the most profitable investment strategies for shipowners, based on the timing to buy or sell a vessel and the market conditions, in the second-hand container shipping market?"
(4) "What is the price premium associated with an alternative-fueled containership?"

To address these research sub-questions, econometric techniques are used to analyse the investment strategies under different market dynamics, fuel efficiency, and alternative fuels that affect asset values and investment decisions in the container liner shipping industry, providing data-driven insights. Data on time-charter rates, vessel characteristics, and vessel prices are collected from industry sources. In the time-charter market, energy efficiency is proxied by the Energy Efficiency Design Index (EEDI) to assess whether more efficient vessels achieve higher earnings, while accounting for vessel size, age, and market conditions. In the second-hand market, the analysis focuses on how time-charter rates affect vessel prices and whether systematic trading strategies outperform long-term holding. In the newbuilding market, individual contracting data are used to estimate the price premium for alternative-fuel technologies such as LNG, methanol, and hybrid propulsion, as well as scrubber installations, relative to conventional containerships, while also considering differences across shipyards and regions.

In the freight market, empirical results show that more energy-efficient containerships command premium rates in their time-charter contracts, with eco-engine vessels achieving even higher premiums, indicating that the time-charter market increasingly values energy efficiency. In the second-hand market, the analysis indicates that time-charter rates have a strong influence on second-hand prices and provide a reliable signal for timing investment and divestment decisions. Moreover, due to higher price volatility, active trading strategies outperform the buy-and-hold strategies for larger vessels, while smaller containerships yield better returns through long-term holding. Finally, in the newbuilding market, vessels with alternative fuels, such as LNG, hybrid, and methanol, are associated with substantial price premiums compared to conventional designs. Notably, China offers lower prices compared to the Republic of Korea and Japan.

Overall, this dissertation suggests that investment strategies should not be solely based on market signals but should fundamentally consider decarbonisation measures. First, energy efficiency is rewarded in the time-charter market through higher rate premiums for energy-efficient and eco-engine vessels. Second, in the second-hand market, vessel prices and investment performance are closely tied to market dynamics and vessel size, with active trading strategies outperforming passive ownership for larger ships, while smaller ships perform better under long-term holding. Third, in the newbuilding market, alternative-fuel technologies such as LNG, methanol, and hybrid propulsion involve significant cost premiums compared to conventional designs, with China offering lower prices than Korea and Japan. Taken together, these findings validate that fuel efficiency and green technologies are now central to asset valuation, time-chartering, second-hand trading, and newbuilding investment decisions in the container liner shipping. Future research should examine how macroeconomic factors, regulatory changes, and geopolitical shifts influence investment strategies across the newbuilding, time-charter, second-hand, and demolition markets, with particular attention being given to retrofitting, charterers' heterogeneous preferences, and the long-term effects of decarbonisation measures on fleet renewal and market interdependencies.

Nederlandstalig Abstract

Navigeren door de groene transitie: Investeringsstrategieën van reders en marktinterdependenties in de containerlijnvaart onder decarbonisatiedruk

Thesis ingediend ter verkrijging van de graad doctor in de toegepaste economische wetenschappen

De containerlijnvaartindustrie speelt een belangrijke rol in de wereldhandel, maar staat onder toenemende druk om de uitstoot van broeikasgassen te verminderen onder de decarbonisatiemaatregelen van de IMO en de EU. In dit verband vertoonden containerschepen consequent het hoogste aandeel CO_2-emissies in de maritieme sector, variërend van 25,4% tot 26,7% tussen 2019 en het derde kwartaal van 2023, waarmee zij behoren tot de grootste uitstoters van broeikasgassen in de internationale scheepvaart (*OECD,2023*). Als grootste uitstoter binnen de scheepvaart staat de containervaart onder verscherpt toezicht en ziet zij zich geconfronteerd met toenemende druk om aan strengere klimaatdoelstellingen te voldoen. Dit creëert nieuwe uitdagingen voor reders, die complexe investeringsbeslissingen moeten nemen onder volatiele marktomstandigheden en regelgevende onzekerheid.

Aangezien reders de belangrijkste stakeholders zijn die investeren in de containerlijnvaart, richt dit proefschrift zich op strategische “groene investerings” beslissingen in drie onderling verbonden markten: de nieuwbouwmarkt, de koop- en verkoopmarkt (S&P) en de vrachtenmarkt (time-charter). Door regelgevende doelstellingen, marktkrachten en technologische ontwikkelingen te integreren, beoogt dit onderzoek de onderlinge afhankelijkheden tussen deze markten te analyseren en te beoordelen hoe investeringsstrategieën kunnen worden vormgegeven onder de druk van decarbonisatie. De sloopmarkt is hierbij bewust buiten beschouwing gelaten, om een diepere en meer gerichte analyse te kunnen maken van de aspecten die rechtstreeks van

invloed zijn op groeikansen, marktuitbreiding en het strategisch beslissingsproces van investeerders en rederijen. De centrale onderzoeksvraag luidt:

"Hoe beïnvloeden marktdynamiek, brandstofefficiëntie en alternatieve brandstoffen, onder de druk van decarbonisatie, de activawaarderingen en investeringsbeslissingen in de containerlijnvaart?"

Om deze vraag te beantwoorden, wordt de analyse in vier deelvragen opgesplitst:

(1) "Welke markttrends en ontwikkelingen zijn zichtbaar in de containerlijnvaartindustrie?"

(2) "Wat is de prijspremie voor brandstofefficiëntere schepen in de time-chartermarkt?"

(3) "Welke investeringsstrategieën zijn het meest winstgevend voor reders, afhankelijk van het aankoop- of verkoopmoment en de marktomstandigheden op de tweedehands containermarkt?"

(4) "Wat is de prijs-premie die samenhangt met een containerschip dat op alternatieve brandstoffen vaart?"

Om deze onderzoeksvragen te beantwoorden, worden econometrische technieken toegepast om investeringsbeslissingen te analyseren onder verschillende marktdynamieken, brandstofefficiëntie en alternatieve brandstoffen die de waarde van activa en investeringsbeslissingen beïnvloeden. Gegevens over time-chartertarieven en scheepskenmerken zijn afkomstig uit de sector. In de time-chartermarkt wordt brandstofefficiëntie gemeten aan de hand van de Energy Efficiency Design Index (EEDI), om te beoordelen of efficiëntere schepen hogere inkomsten genereren, rekening houdend met scheepsgrootte, leeftijd en marktomstandigheden. In de tweedehandsmarkt wordt de relatie tussen activawaarden en charterprestaties geanalyseerd om vast te stellen hoe time-chartertarieven prijzen beïnvloeden en of systematische handelsstrategieën beter presteren dan langetermijnbezit. In de nieuwbouwmarkt worden contractgegevens gebruikt om de meerkosten te schatten van technologieën voor alternatieve brandstoffen zoals LNG, methanol en hybride voortstuwing, evenals scrubbers, vergeleken met conventionele ontwerpen, met inachtneming van verschillen tussen werven en regio's.

In de vrachtenmarkt tonen de empirische resultaten aan dat energiezuinigere containerschepen een premie realiseren in hun time-chartercontracten, waarbij schepen met eco-motoren nog hogere premies behalen. Dit wijst erop dat de chartermarkt in toenemende mate waarde hecht aan energie-efficiëntie. In de tweedehandsmarkt laat de analyse zien dat time-chartertarieven een sterke invloed hebben op de prijzen en een betrouwbare indicator vormen voor het moment van investeren en desinvesteren. Bovendien presteren actieve handelsstrategieën, vanwege de hogere prijsvolatiliteit, beter dan buy-and-hold-strategieën voor grotere schepen, terwijl kleinere containerschepen op de lange termijn betere rendementen behalen bij aanhouden. Ten slotte zijn in de nieuwbouwmarkt schepen op alternatieve brandstoffen zoals LNG, methanol en hybride voortstuwing verbonden aan aanzienlijke meerkosten ten opzichte van conventionele ontwerpen, hoewel deze variëren per regio, waarbij China lagere instapkosten biedt dan Zuid-Korea en Japan.

Samenvattend suggereert dit proefschrift dat investeringsstrategieën niet uitsluitend gebaseerd mogen zijn op marktsignalen, maar fundamenteel rekening moeten houden met decarbonisatiemaatregelen. Ten eerste wordt energie-efficiëntie beloond in de time-chartermarkt via hogere tarieven voor efficiënte en eco-schepen. Ten tweede zijn in de tweedehandsmarkt scheepsprijzen en investeringsresultaten nauw verbonden met charterdynamiek en scheepsgrootte, waarbij actieve handelsstrategieën beter presteren voor grotere schepen, terwijl kleinere schepen meer voordeel halen uit langetermijnbezit. Ten derde brengen in de nieuwbouwmarkt technologieën op alternatieve brandstoffen zoals LNG, methanol en hybride voortstuwing aanzienlijke meerkosten met zich mee ten opzichte van conventionele ontwerpen, al variëren deze premies tussen scheepswerven, met lagere kosten in China dan in Zuid-Korea en Japan. Alles samen bevestigen deze bevindingen dat brandstofefficiëntie en groene technologieën nu centraal staan in de waardering van activa, het charteren, de handel en de nieuwbouwbeslissingen in de containerlijnvaart. Toekomstig onderzoek zou moeten nagaan hoe macro-economische factoren, regelgevende veranderingen en geopolitieke verschuivingen investeringsstrategieën beïnvloeden in de nieuwbouw-, time-charter-, tweedehands- en sloopmarkten. Bijzondere aandacht dient uit te gaan naar retrofitten, de heterogene voorkeuren van charterers en de langetermijneffecten van decarbonisatiemaatregelen op vlootvernieuwing en marktinterdependenties.

Chapter 1: Introduction

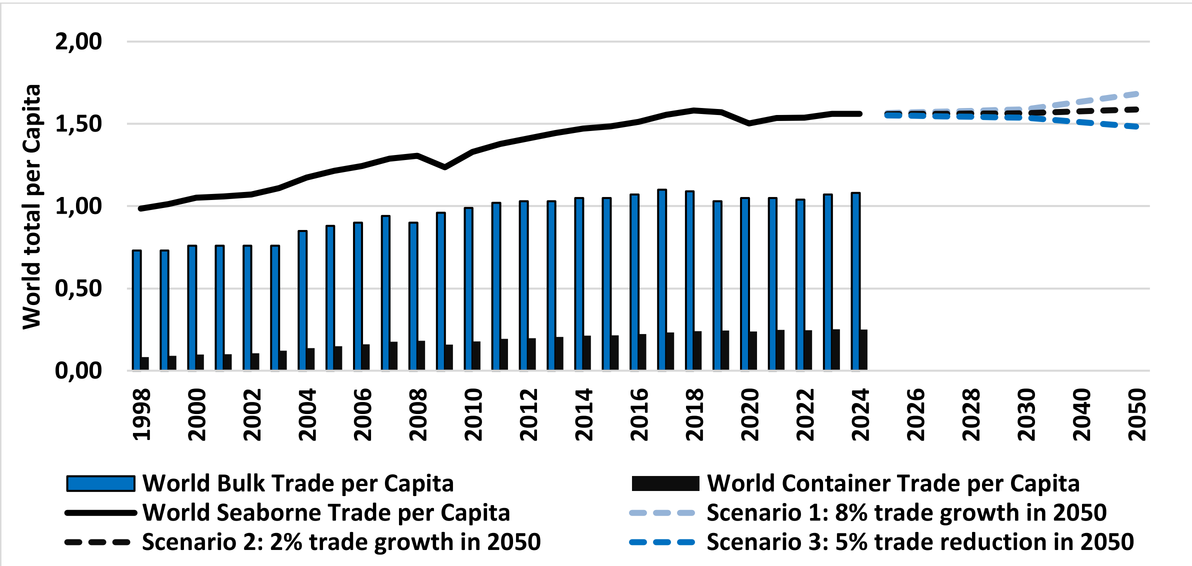
The container liner shipping industry plays an important role in global trade, representing approximately 16% of global capacity in deadweight (DWT) terms . However, the shipping industry faces increasing pressure to reduce its environmental impact in line with International Maritime Organisation (IMO) and EU decarbonisation targets. This has introduced new challenges for shipowners, who must make complex investment decisions under volatile market conditions and regulatory uncertainty. This chapter presents the primary research question that drives this doctoral dissertation. Section 1.1 provides the research background and context of the study. Section 1.2 outlines the main problem and states the aim of the research. Section 1.3 presents the main research question, the scope of the study, the methodological approach, and the study's innovations. Finally, Section 1.4 summarises the structure of the dissertation.

1.1 Research Background

The shipping industry plays an important role in the world economy, and it is considered one of the most crucial transportation modes, as it is responsible for 86% of global trade (Clarkson's Research, 2025). It is characterised as a derived demand, with its growth and activity impacted by global economic conditions, international trade flows, consumption patterns, and regulatory measures (Stopford, 2009). Three noticeable megatrends can be identified: firstly, the demographic shifts, such as population growth and trade rerouting triggered by geopolitical tensions; secondly, the transition towards sustainable practices; and thirdly, advancements in technological innovation in the shipping industry. Collectively, these trends, among other factors, exert a significant influence on the investment decisions of shipowners (Stopford, 2009).

Starting from the demographic changes, according to the United Nations (2024), the global population has continued to grow, reaching approximately 8.2 billion people in 2024, and is projected to rise to 9.7 billion by 2050, with China and India anticipated to be major drivers of global economic growth, creating the necessity for additional vessel capacity tonnage, able to meet the global demand. Figure 1.1 illustrates the world's seaborne trade from 1998 to 2024 for bulk and containerised products per capita, and it also presents three alternative scenarios for the expected seaborne trade until 2050. It can be observed that, despite the small reductions one year after the 2008 economic crisis, the supply disruptions from COVID-19 and other geopolitical disturbances, there has been a continuous increase in world seaborne trade. Considering the continued population and economic growth, one realistic scenario is the growth in seaborne trade by about 2% per capita till 2050 (Clarkson's Research, 2025). However, technological development may lead to an even further increase in world trade (i.e., 8% growth in 2050), while in one pessimistic scenario, there is a reduction in trade (i.e., a 5% reduction in 2050). Even in such a scenario, it is indicated that these changes will result in the introduction of new and possibly larger-capacity vessels, which will be required to operate in a sustainable environment.

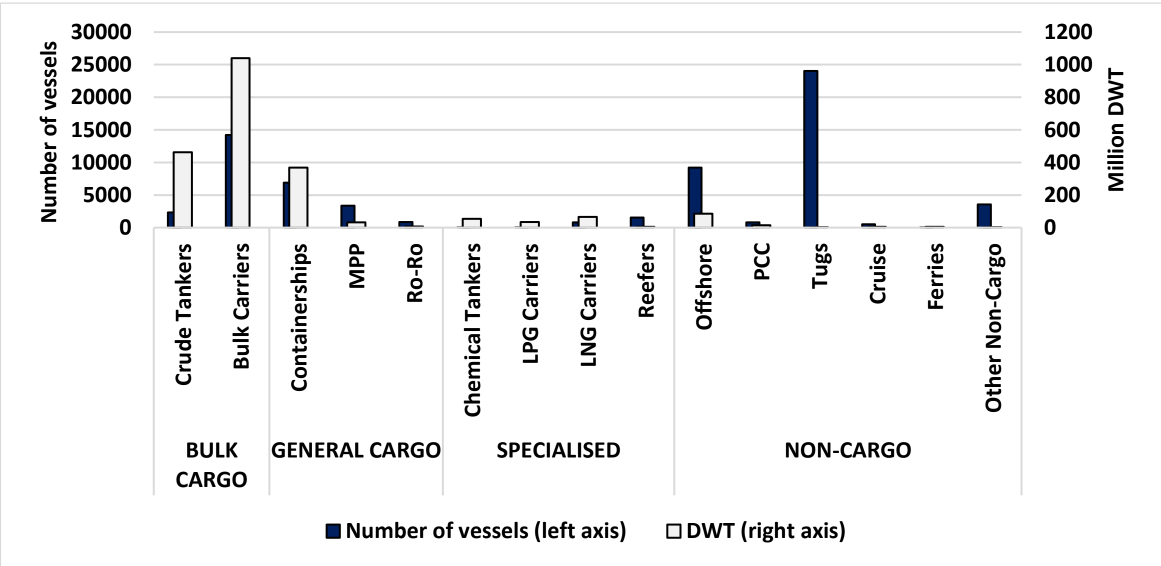
Figure 1.1: World seaborne trade



Source: Own compilation based on Clarkson's Research NV (2025)

In the maritime industry, containerships were introduced as a revolutionary transportation mode, able to handle general cargo through automation and standardisation processes, offering reliable service on fixed schedules and routes across major ports, with sizes ranging from small feeder containerships (up to 3,000 TEUs) to Post-Panamax vessels (up to +17,000 TEUs), primarily for international trade (Levinson, 2016). The term twenty-foot equivalent unit (TEU), which applies only to containerships, refers to the standard measurement of the vessel capacity, based on a single 20-foot container. However, to provide a uniform measure of carrying capacity across all vessel types, Figure 1.2 presents an overview of the global maritime fleet as of February 2025, in terms of vessel numbers and deadweight tonnage (DWT) across major shipping segments. It is distinguished that while dry bulk carriers and tankers continue to dominate in terms of fleet size and tonnage, containerships remain one of the pillars of the global maritime segments. As of February 2025, the container liner shipping industry maintained 6,880 vessels, accounting for up to 367 million DWT, representing 16,83% of the global fleet DWT capacity (Clarksons Research, 2025).

Figure 1.2: Global fleet overview in February 2024



Source: Own compilation based on Clarkson's Research NV (2025)

Secondly, concerning the sustainability aspects, one of the most significant issues related to the shipping industry is the environmental impact caused by the vessel's operations. According to IMO Fourth GHG Study (2020), in 2018, the shipping industry was responsible for approximately 2.89% of global anthropogenic GHG emissions, corresponding to about 1,076 million tonnes (Mt) CO_2 equivalent. Beyond carbon dioxide, shipping is also a major source of sulphur oxides (SO_x), nitrogen oxides (NO_x), and methane (CH_4), while based on *OECD (2025*) international GHG emissions continue to be dominated by the three main vessel types (tankers, bulk carriers, and containers), which, as of the third quarter of 2023, accounted for 82% of international shipping emissions, with the container shipping segment being the main GHG emission contributor.

As the largest emitter within the shipping industry, container shipping is under scrutiny and feels increased pressure to meet stricter climate targets[1]. Traditionally, shipping investment decisions were primarily driven by market conditions, such as freight rate volatility, ship prices, and shipowners' expectations of future demand (Kavussanos, 2003; Stopford, 2009). However, over the last decade, shipowners' investment decisions have needed to be based on more sustainable practices that can meet the IMO and EU decarbonisation targets. These regulatory developments, including measures such as the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII), which will be further discussed in Essay 2.4, are reshaping investment behaviour across the container shipping sector (Pruyn, 2020; Pang et al., 2021). Furthermore, maritime transport entered the EU Emissions Trading System in 2024, covering 40% of emissions, with the coverage rising to 100% by 2026, thereby increasing the costs for less efficient vessels. Moreover, from 2025, the FuelEU Maritime regulation will require a 2% cut in fuel GHG intensity, rising to 80% by 2050 (European Commission, 2023), while according to the Carbon Border Adjustment Mechanism (CBAM), starting in 2026, additional carbon costs

[1] That is why this Doctoral Thesis focuses on this shipping segment.

on imported shipbuilding materials like steel will potentially increase the cost for fossil-fuel vessels and incentivise investment in low-carbon designs in European shipyards (European Commission, 2025). To this extent, although most containerships are built in Asia and are not directly covered by CBAM measures, this policy increases global pressure on steelmakers to decarbonise, which in turn encourages Asian shipyards and shipowners to adopt low-carbon designs. To this extent, Compernolle et al. (2022) examined how firms choose between carbon taxes and emissions trading systems (ETS), indicating that when carbon and electricity prices are positively correlated, ETS systems can actually accelerate investment in low-carbon technologies by reducing total investment risk. However, in highly uncertain or volatile environments, carbon taxes are more effective at discouraging carbon-intensive investments. In the case of shipping, the inclusion of the sector in the EU ETS reflects the exposure to carbon prices, making less energy-efficient vessels more costly and pushing shipowners towards alternative-fuel and more energy-efficient vessels.

Thirdly, technological innovations, including the implementation of green shipping practices and eco-friendly technologies, have become an important domain for the shipping industry's sustainability and growth (Aronietis et al., 2015; J. Pruyn, 2017; Stevens et al., 2015; Sys and Tei, 2024). These measures include operational strategies such as low speed, alternative fuels, and technological upgrades to the existing fleet, such as exhaust gas cleaning systems (scrubbers) and eco-vessel designs (Lindstad and Eskeland, 2015; Panasiuk and Turkina, 2015). Eco-design refers to new generations of ships built with optimised hull forms, energy-efficient engines, and propulsion improvements that reduce fuel consumption and emissions compared to earlier designs. In the case of the dry bulk market, Pruyn (2020) indicated that vessels built after 2013 also showed improved propulsion efficiency and higher energy efficiency, particularly larger vessels, indicating compliance through both technological innovation and strategic speed optimisation. However, focusing on bulk carriers, the author did not consider the case of containerships, which remains the main contributor to GHG emissions.

Overall, the feasibility of adopting these technological innovations is strongly influenced by factors including vessel type and age, regional fuel availability, and the presence of adequate bunkering infrastructure, creating substantial challenges for shipowners and investors (Acciaro et al., 2014; Poulsen et al., 2018; Mallouppas and Yfantis, 2021).

As a result, decision-making around operational strategies and “green investments” has become increasingly complex. In the maritime industry, green investment refers to the transition of the maritime sector toward environmentally sustainable practices through technological, operational, and regulatory measures aimed at reducing GHG emissions and environmental impact (OECD, 2013). While the term is often linked to broader financial frameworks such as Environmental, Social, and Governance (ESG) or Socially Responsible Investing (SRI), in the maritime sector, it refers specifically to technical and operational strategies undertaken to comply with environmental regulations and to enhance long-term competitiveness (OECD, 2013). Tsatsaronis et al. (2024) also proposed a new ESG index for shipping and found that it improves sustainability benchmarking and informs strategic decision-making by integrating environmental and governance dimensions, suggesting that strategic planning in shipping and infrastructure development must consider both market conditions and stakeholder dynamics to effectively deal with market uncertainty.

1.2 Problem Statement and Research Objective

While the maritime sector makes a significant contribution to global trade, one of the most significant issues related to the shipping industry is the environmental impact caused by the vessel’s operations. According to IMO Fourth GHG Study (2020) in 2018, the shipping industry was responsible for approximately 2.89% of the global CO_2 emissions, corresponding to about 1,076 million tonnes (Mt) CO_2 equivalent. Beyond carbon dioxide, shipping is also a major source of sulphur oxides (SO_x), nitrogen oxides (NO_x), and methane (CH_4), while based on *OECD (2025*) international greenhouse gas (GHG) emissions continue to be dominated by the three main vessel types (tankers, bulk carriers, and containers), which, as of the third quarter of 2023, accounted for 82% of international shipping emissions. Between 2019 and 2024, container CO_2-equivalent emissions fluctuated sharply, with the sector experiencing a notable decrease in 2020 due to the COVID-19 pandemic's disruption of global trade, followed by a strong rebound and record-breaking levels in 2024, when emissions surged to roughly 240 million tonnes of CO_2 (see Figure 2.19)

In response to growing concerns over maritime GHG emissions, the International Maritime Organisation (IMO), a specialised agency of the United Nations responsible for improving the maritime industry's security and safety and preventing pollution from ships, adopted a GHG reduction strategy in 2018, which combines technical and operational efficiency measures, aiming to reduce total annual GHG emissions from international shipping by at least 50% by 2050 compared to 2008 levels. In July 2023, the IMO revised its initial strategy, which was further reinforced in MEPC 83, and set new targets of a 40% reduction in carbon intensity by 2030, the adoption of low- and zero-emission fuels reaching 5–10% by 2030, and net-zero GHG emissions by 2050, through operational and technological measures (IMO, 2025).

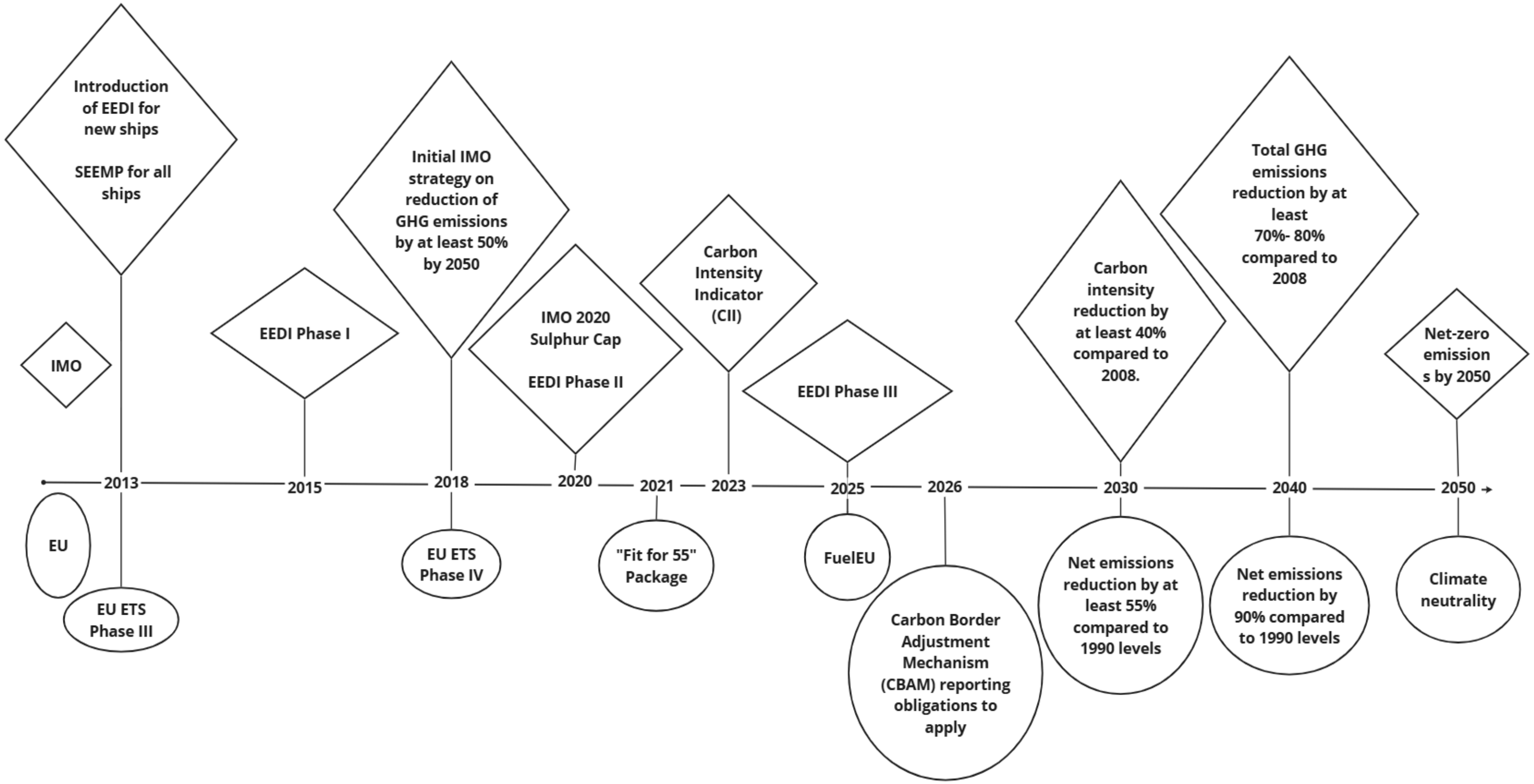
One of the key measures includes the Energy Efficiency Design Index (EEDI), which was formally adopted during the 62nd session of the *Marine Environment Protection Committee (MEPC 62)* through amendments to MARPOL Annex VI, addressing air pollution from ships (IMO, 2022). Effective on January 1, 2013, these amendments mandate progressively stricter EEDI standards for new vessels to reduce CO_2 emissions in international shipping. EEDI implementation began with Phase 0 (2013–2015), establishing baseline efficiency levels, while subsequent phases introduced increasingly stringent targets, with Phase 1 (2015–2019) required a 10% improvement, and Phase 2 (2020–2024) raised this to 20%, while Phase 3, starting from January 2025, aims for CO_2 emissions reduction up to 30%, depending on ship type and size. An additional measure introduced by the IMO is the annual operational Carbon Intensity Indicator (CII) rating[2], which requires vessels to assess and report their operational carbon intensity. The CII measures the ship's energy efficiency

[2] There is ongoing debate about the effectiveness and fairness of the CII framework, particularly concerning its focus on operational metrics like distance sailed rather than cargo carried, which may disadvantage certain vessel types or trade routes.

in grams of CO_2 per cargo-carrying capacity and nautical mile, rating a vessel from A (major superior/ most efficient) and B (minor superior), to C (moderate), D (minor inferior), and E (inferior/least efficient), with progressively tightened rating thresholds through 2030. A ship rated D for three consecutive years or E once must update its Ship Energy Efficiency Management Plan (SEEMP) with a Corrective Action Plan (CAP) that outlines how the ship will achieve at least a C rating in future years (IMO, 2022).

In parallel, in 2021, the European Commission introduced the “Fit for 55” package, which aims to reduce emissions by 55% relative to 1990 levels by 2030 and achieve climate neutrality by 2050 (European Commission, 2021), while in 2024, maritime transport entered the EU Emissions Trading System, covering 40% of verified emissions from applicable ships, rising to 100% by 2026 (European Commission, 2023). Furthermore, EU carbon allowance prices are expected to raise costs for conventional vessels (Reuters, 2024), while from 2025, the FuelEU Maritime regulation will require a 2% cut in fuel GHG intensity, rising to 80% by 2050 (European Commission, 2023). Moreover, the Carbon Border Adjustment Mechanism (CBAM), starting in 2026, will add carbon costs on imported shipbuilding materials like steel (European Commission, 2025), increasing the cost for fossil-fuel vessels and incentivising investment in low-carbon designs. Figure 1.3 provides a timeline of the IMO and EU regulations related to decarbonisation.

Figure 1.3: IMO and EU regulations toward shipping emission neutrality



Source: Own compilation based on IMO and EU regulations toward shipping emission neutrality

These developments, including regulatory measures such as the EEDI, the CII, and the EU ETS, are reshaping investment behaviour across the container shipping sector (Pruyn, 2020; Pang et al., 2021). Traditionally, shipping investment decisions were primarily driven by market conditions, such as freight rate volatility, ship prices, and shipowners' expectations of future demand (Kavussanos, 2003; Stopford, 2009). Additionally, as the approximate time to build a vessel is 2-3 years, with a life expectancy of up to 25-30 years, a common pattern observed was the anti-cyclical nature of investment behaviour, as shipowners would often aim to purchase vessels when prices were low, aiming to maximise profits based on market conditions and the investment timing (Alizadeh and Nomikos, 2007; Stopford, 2009; Gkochari, 2015; Ferrari et al., 2018).

Along with this, over the last decade, the decarbonisation of container liner shipping has been increasingly reliant on the adoption of alternative fuels such as liquefied natural gas (LNG), methanol, ammonia, and hydrogen, while additional measures include operational strategies such as low speed, and technological upgrades to the existing fleet, such as exhaust gas cleaning systems (scrubbers) and eco-vessel designs (Aronietis et al., 2015; J. Pruyn, 2017; Stevens et al., 2015; Sys and Tei, 2024). To this extent, the IMO introduced Lifecycle Assessment (LCA) guidelines for marine fuels, establishing a standardised framework to evaluate GHG emissions across the entire energy supply chain. The guidelines distinguish between the "well-to-tank" phase, which captures upstream emissions from fuel extraction, processing, and delivery to the vessel, and the "tank-to-wake" phase, which covers the emissions released during fuel combustion on board, ensuring that efforts to decarbonise shipping prevent a shift of environmental impacts to other sectors (IMO, 2024).

Based on this, Zhao et al. (2025) indicated that these fuels present different opportunities and challenges. LNG reduces CO_2 emissions compared to conventional fuels but suffers from methane slip. Methanol offers easier handling but has lower energy density and variable lifecycle emissions, whereas ammonia and hydrogen could provide zero CO_2 emissions but face challenges related to toxicity, storage requirements, and infrastructure readiness. Importantly, green hydrogen and green ammonia can achieve deep lifecycle reductions, but their high costs and limited supply restrict their competitiveness in the absence of carbon pricing or incentives. At the same time, additional technologies such as onboard carbon capture and storage (CCS), wind-assisted propulsion, and optimized hull and propeller designs can further reduce the total climate impact of shipping (Kondratenko et al., 2025)[3].

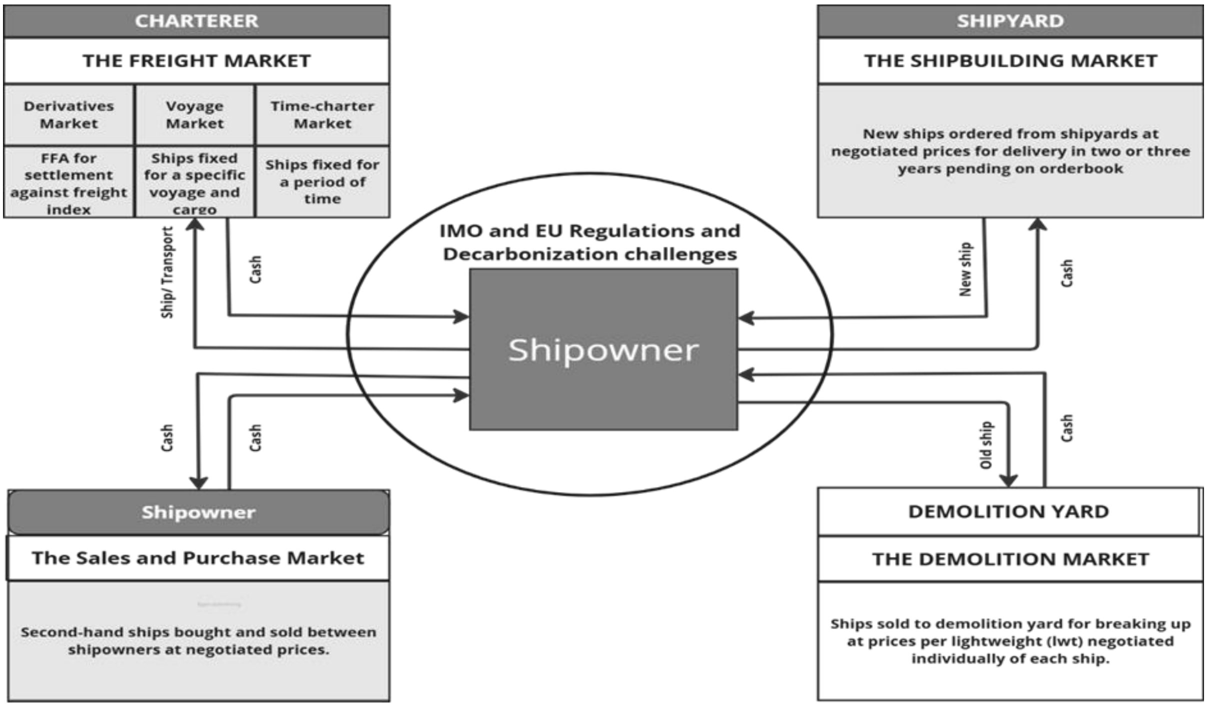
Therefore, it is evident that the transition toward low-carbon shipping is a complex balance of fuel availability, technological and port infrastructure readiness, environmental performance, and economic feasibility, with methanol and LNG acting as immediate practical options, while ammonia and hydrogen represent strategic long-term solutions depending on infrastructure and regulatory progress.

1.3 Scope of the Study, Research Questions, Methodology, and Innovations

Given the fact that container shipowners are the main stakeholders investing in the maritime container liner shipping industry, the study focuses on strategic "green investment" decisions, on three interrelated markets in which shipowners operate: the newbuilding market, the sales and purchase (S&P) market, and the freight (time-charter) market, each of which is impacted by the decarbonisation pressures, (Figure 1.4).

[3] A more detailed discussion of emission profiles and lifecycle impacts is provided in Essay 2.4.1.

Figure 1.4: The four shipping markets



Source: Own composition based on Stopford (2009)

Each of these markets plays a distinct role in the shipping industry, offering advantages and challenges for shipping investors and shipowners. Firstly, the time-charter market plays a key role in generating revenue and often influences investment decisions, prompting container shipping investors to purchase a second-hand vessel, which often offers immediate capacity, or order a new ship in the new-building market. Furthermore, entering a time-charter contract can be regarded as an investment decision, as shipowners allocate their assets for a fixed period in return for expected revenues, while they may also act as charterers themselves, hiring in vessels from other owners to expand their fleet capacity or to cover short-term demand without committing to newbuilding or second-hand acquisitions (Stopford, 2009). Secondly, the S&P market allows for flexible, timing-based investment strategies as asset values fluctuate with market cycles and regulatory developments and provides direct capacity access in the market. It also reduces the barriers to entering the market due to lower capital commitment compared to the newbuilding market, where investment costs typically are higher and delivery times are longer, as a vessel may require up to 2 – 3 years to be built (Alizadeh and Nomikos, 2007; Stopford, 2009). Thirdly, the newbuilding market enables shipowners to future-proof their fleets by adopting energy-efficient technologies or alternative fuel capabilities, although this typically involves even higher capital requirements and longer delivery times (Stopford, 2009; Mohseni et al., 2019; Al-Enazi et al., 2021). Notably, these three markets are interdependent. For example, a shipowner might purchase a second-hand vessel for direct capacity availability, or alternatively, they may order a new vessel if they anticipate future growth in freight rates or when they require specific vessel features not directly available in the second-hand market. As decarbonisation pressures intensify, choices in the time-charter, second-hand, and newbuilding markets are increasingly influenced by environmental regulations (Rojon et al., 2021; Xue et al., 2024). Thus, shipowners must take an integrated approach across these markets, carefully aligning their investment timing and asset choices not only with short-term opportunities but also with long-term decarbonisation and sustainability targets (Baştuğ et al., 2024).

Therefore, this doctoral thesis aims to explore how container shipowners can make informed investment decisions in the three major operating shipping markets: the freight (time-charter) market, the sales and purchase market, and the newbuilding market. In this context, investment refers not only to the acquisition of vessels in the second-hand and newbuilding markets, but also to the commitment of vessel capacity in the time-charter market. By integrating regulatory targets, market dynamics, and technological advancements, the study seeks to understand the interdependencies between these markets and assess how investment strategies can be considered by shipowners and investors. The main research question that guides this study is:

MQ: "In the context of decarbonisation pressures, how do market dynamics, fuel efficiency, and alternative fuels affect asset values and investment decisions in the container liner shipping industry?"

The primary aim of this doctoral dissertation is to analyse how investment strategies are shaped under IMO and EU decarbonisation pressures by examining the interdependencies among the time-charter markets, second-hand markets, and newbuilding markets. Understanding how investment decisions are formed within this context is important for assessing how the shipping industry can effectively adapt to the requirements of IMO and EU decarbonisation targets. To address the main research question, this doctoral dissertation is decomposed into four distinct sub-questions, each addressing a specific dimension of the central research problem.

The first study examines the market trends, developments, and challenges within the container shipping industry to gain insight into the investment strategies adopted by container market participants. Specifically, the first study addresses the following research sub-questions (SQs):

SQ1: *Which market trends and developments have been observed, and which are the challenges in the container liner shipping industry?*

Understanding the market dynamics and evolution across the four segments of the container shipping market is essential for analysing how shipowners' investment behavior is shaped in response to regulatory pressures, economic conditions, and evolving technological trends.

Considering the current market trends and developments mentioned above, the second empirical study focuses on the time-charter market as the primary source of revenue for shipping companies. In the time-charter market, the charterer hires a ship from a shipowner

(owner of the vessel) at a fixed rate, meaning that the shipowner is paid on a $/day or lump sum for the duration of the hire period (Pagonis and Pentheroudakis, 2019). In container liner shipping, time chartering is a strategic tool used by operators to secure flexible capacity, particularly in response to volatile trade volumes and supply chain disruptions (Plomaritou and Menelaou, 2020). For shipowners, time charters also provide steady cash flow, which is increasingly critical given the capital investments required for compliance with evolving environmental regulations, while they may also act as charterers themselves to cover short-term demand without committing to newbuilding or second-hand purchases. To this extent, regulatory uncertainty also influences these strategies, as shipowners may prefer to charter in more efficient vessels rather than commit to ownership(Adland et al., 2017).

Given the IMO's intensified measures to reduce GHG emissions, extensive discussions have emerged regarding the adoption of greener technologies to enhance the industry's commitment to sustainable practices. Additionally, it is still being determined whether the push towards making containerships more energy-efficient and environmentally friendly financially benefits shipowners. Therefore, the second empirical study investigates the following sub-question:

SQ2: *What is the price premium for more fuel-efficient vessels in the time charter market?*

Consequently, this empirical study of this dissertation examines whether more energy-efficient containerships financially benefit shipping owners by commanding premium rates in time-charter contracts. Focusing on the post-COVID-19 period, the study also covers the period during which decarbonisation pressures have intensified and environmental performance has become more significant.

The third empirical study investigates the trading strategies in the sales and purchase market in the container shipping segment. The second-hand market is a place where participants commonly include shippers, shipowners, and investors who also trade in other shipping market sectors. The sales and purchase market is characterized as a market with high price volatility, where investors can achieve profits from the good timing of selling and purchasing activities, known as "asset play" (Merikas et al.. In the container liner shipping market, Jia et al. (2024) confirmed the presence of a green price premium for second-hand container eco-ships, with financial buyers, who typically act as lessors, presenting a more pronounced inclination towards investing in container eco-ships compared to operating buyers. Nevertheless, the topic of exploiting potentially profitable opportunities arising from vessel trading in the sales and purchase container shipping market has not been adequately researched, particularly in light of the uncertainty regarding decarbonisation targets. Thus, the third sub-research question that drives this dissertation is the following.

SQ3: *Which are the most profitable investment strategies for shipowners, based on the timing to buy or sell a vessel and the market conditions, in the second-hand container shipping market?*

The aim of the third study is to examine the performance of negotiation strategies based on technical trading rules and fundamental analysis in the second-hand container shipping market, giving attention to small and medium-sized container vessels.

The fourth empirical study focuses on the newbuilding market, which is considered the primary entry point for technological progress and regulatory compliance in the container liner shipping sector. In the new building market, fleet renewal and investment in new tonnage are impacted by both market cycles and regulatory drivers (Michail and Melas, 2023). In this context, environmental considerations have become increasingly influential in new building investments, particularly in response to stricter regulations and decarbonisation efforts. On top of that, the adoption of alternative fuels is also shaping new building investment strategies, with LNG, methanol, ammonia, and other synthetic fuels being the focus of the research (Brynolf et al., 2014; Schinas and Butler, 2016; Inal et al., 2022). Building on these studies, the third empirical research estimates the cost-premium on new-building prices for alternative fuel containerships, and it contributes to the existing literature by examining the following research question:

SQ4: “*What is the cost premium associated with alternative fuel container vessels?”*

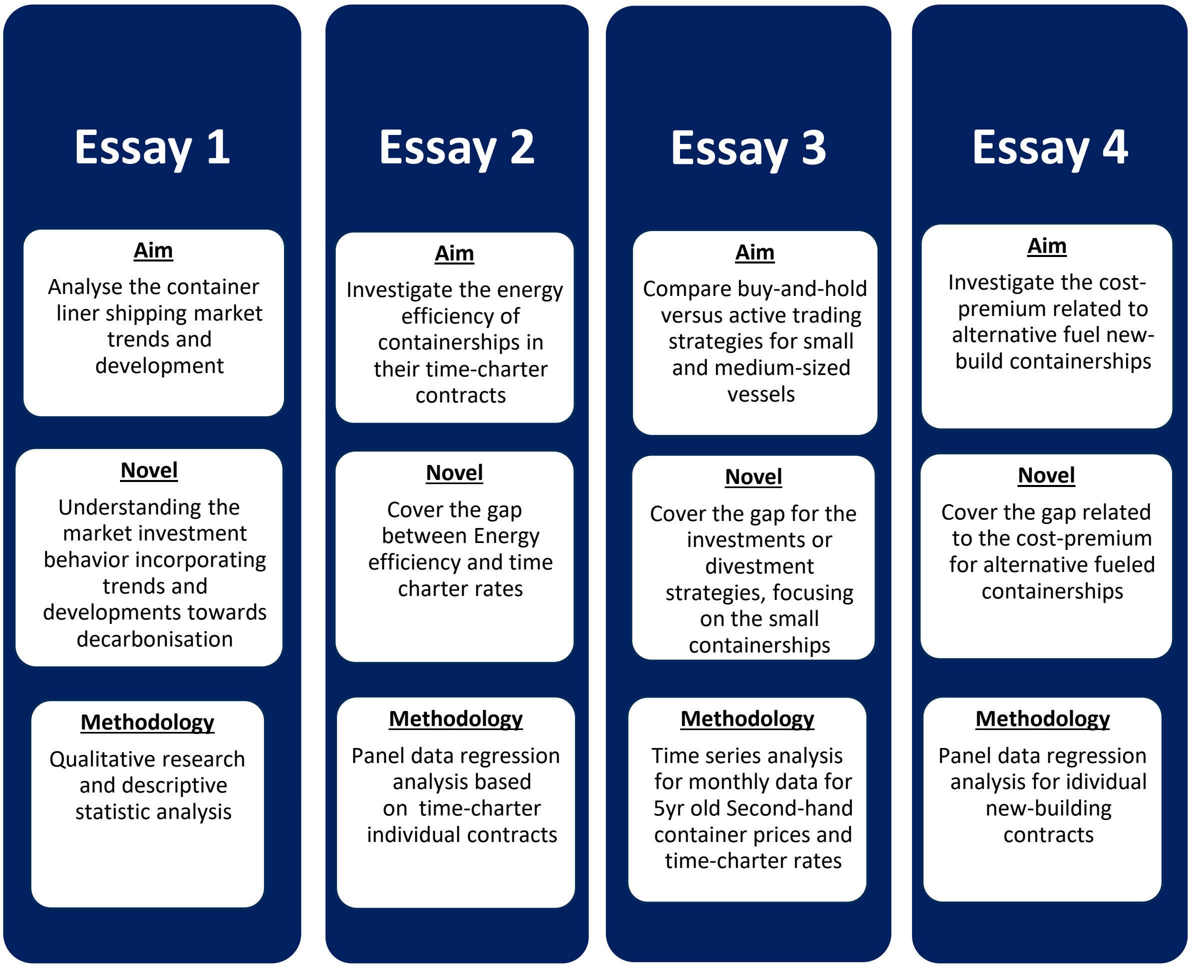
Given the advanced technological requirements of alternative fuel-capable vessels, higher associated costs are anticipated (Solakivi et al. 2022). By analysing individual new-building container ship contracts, this study provides insights into the cost implications of adopting green technology within the context of the IMO and EU decarbonisation targets.

Overall, this doctoral dissertation aims to understand investment decisions in the maritime sector from the shipowners' perspective, conducting individual literature reviews for the three shipping markets (Stopford, 2009). With a focus on the new-building, freight, and sales and purchase markets for container shipping, this study deliberately omits the demolition market to prioritise areas with the most direct impact on active market dynamics, investment strategies, and operational efficiencies within the industry. The rationale behind this decision lies in the distinct nature of the demolition market, which, while integral to the vessel lifecycle, operates under a significantly different set of regulatory, environmental, and labour considerations. Therefore, concentrating on the three selected markets enables a deeper and more focused analysis of the aspects that directly influence growth opportunities, market expansion, and the strategic decision-making process of investors and shipping companies. In parallel, retrofitting has also emerged as an intermediate strategy, allowing shipowners to upgrade existing vessels with dual-fuel engines or fuel cells, with retrofit costs range between USD 600–1,500 per kW for dual-fuel conversions and up to USD 2,600 per kW for fuel cell systems, depending on the fuel type and storage requirements, with LNG and methanol retrofits already being commercially viable, while ammonia and hydrogen remain at the early stage (W. Zhang et al., 2025). However, technical challenges exist, as dual-fuel LNG engines require cryogenic storage, methanol and ammonia handling necessitate toxicity and safety management, and hydrogen demands high-pressure containment, all of which complicate retrofitting projects. However, due to the limited availability of consistent vessel-level data, this study does not explicitly account for retrofitting strategies.

Econometric modelling will be used to analyse the three markets in the container shipping industry, as it offers significant advantages, providing data-driven insights for comprehensively analysing the industry's complexities. The empirical analysis will be conducted using EViews 10. This approach is particularly effective in evaluating various impacts, such as IMO and EU regulations related to decarbonisation, which are essential for informed future policy decisions. Additionally, its customizability ensures relevance and practical application in the industry, as it supports informed investment decisions and risk assessments in response to market, regulatory, and environmental changes.

Figure 1.5 summarises the research design and methodological structure across Essays 1 to 4. More specifically, Essay 1 provides a qualitative, exploratory analysis of the freight, second-hand, and newbuilding markets, identifying the main decarbonisation challenges for the container liner shipping industry. Building on these observations, three regulatory scenarios are developed to frame the empirical analysis. To this extent, Essay 2 examines the price premiums for eco-engine and energy-efficient containerships. Essay 3 examines the profitability of trading strategies in the second-hand market through econometric analysis, while Essay 4 provides one of the first vessel-level data econometric estimates of cost premiums for alternative-fuel and scrubber-fitted vessels in the newbuilding market.

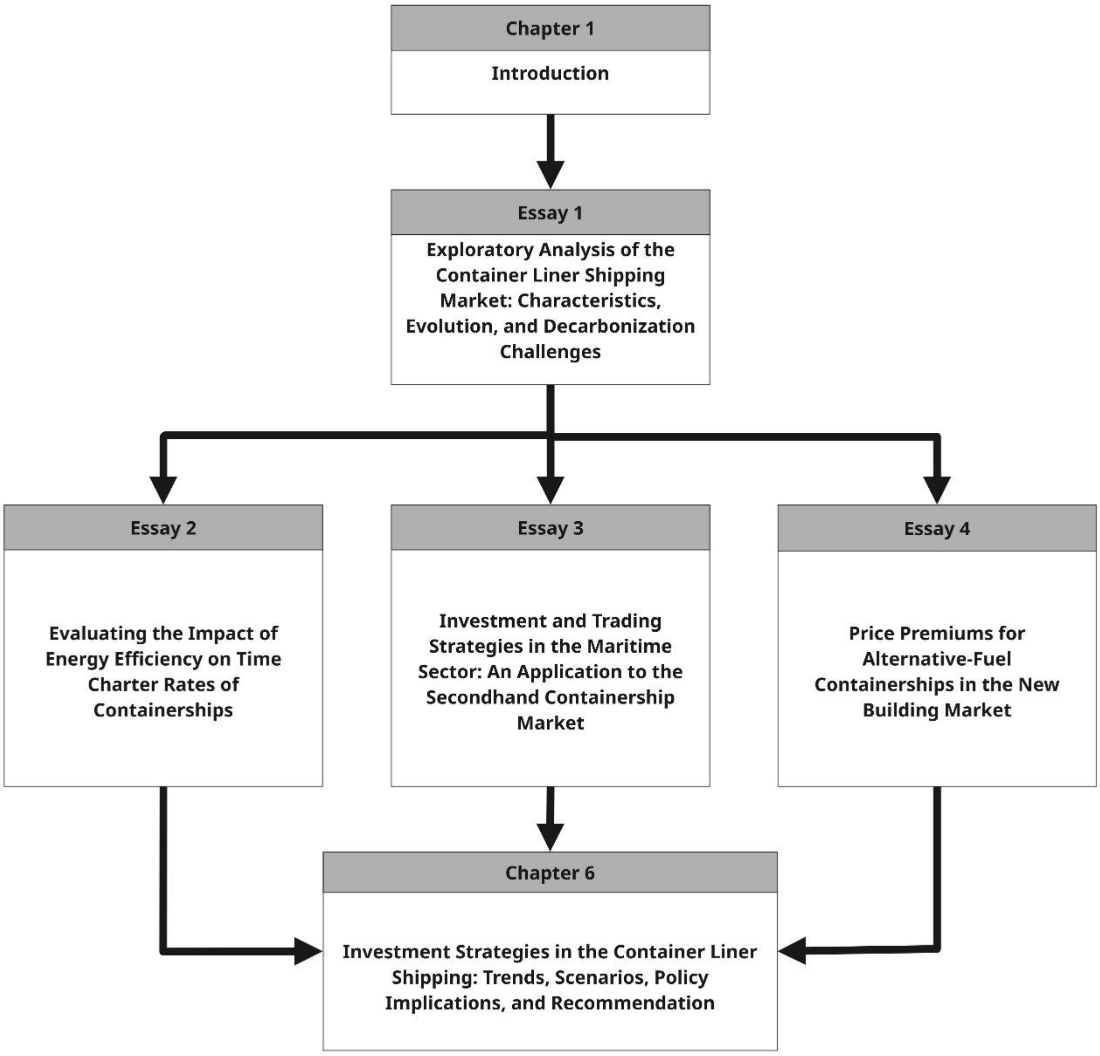
Figure 1.5: Research Framework by essays. Aims, Novel Contributions, and Methodologies for the Container Shipping Market Analysis



1.4 Ph.D. Structure

The Ph.D. thesis investigates the investment strategies in the container shipping industry under the influence of the IMO and EU regulations and the decarbonisation challenges. The thesis will consist of six chapters (including the introduction chapter), each addressing a specific aspect of the research problem (Figure 1.6).

Figure 1.6: Structure of the thesis



More specifically, Essay 1 provides an overview of the three core markets (S&P, new building, and freight market), aiming to offer a basic understanding of the container shipping market dynamics and the drivers of investment and divestment decisions. Essay 2 examines whether more fuel-efficient containerships receive higher time-charter rates, investigating how vessel characteristics, such as age, size, and fuel efficiency, impact time charter earnings. Essay 3 investigates whether investment performance can be enhanced through systematic investment or divestment strategies, focusing on small and intermediate containerships, as those vessel sizes are the main candidates in the second-hand market. Essay 4 examines the price premium for green technologies, such as LNG, methanol, hybrid propulsion, and scrubbers, compared to conventional vessels in the new-building market. Finally, Chapter 6 synthesizes the main empirical findings, draws on the regulatory scenarios developed in Essay 1, and formulates recommendations for shipowners and investors. This doctoral dissertation concludes with a discussion of research limitations and directions for future research.

Chapter 2: Essay 1 - An Exploratory Analysis of the Container Liner Shipping Market: Market Characteristics, Evolution, and Challenges Towards Decarbonisation

This essay provides an overview of the container liner shipping sector and offers a brief analysis of the three core shipping markets, where investment decisions are significantly influenced by decarbonisation measures. Main findings suggest that the container liner shipping segment remains the primary contributor to GHG emissions, with further action required to meet the decarbonisation targets. The study also highlights the impact of economic conditions, regulatory pressures, and geopolitical events (e.g., COVID-19, Red Sea crisis) on the time-charter, second-hand, and new-building container shipping markets. In recent years, alternative fuel-capable vessels have emerged as a promising solution for decarbonisation. Additionally, it is indicated that the industry remains dominated by the top 10 carriers, whose investment strategies and operational preferences strongly shape the market's profile. Nevertheless, there is no unified approach for alternative fuel vessel selection among the top shipowners, illustrating the market complexities and the uncertainty amid decarbonisation pressures.

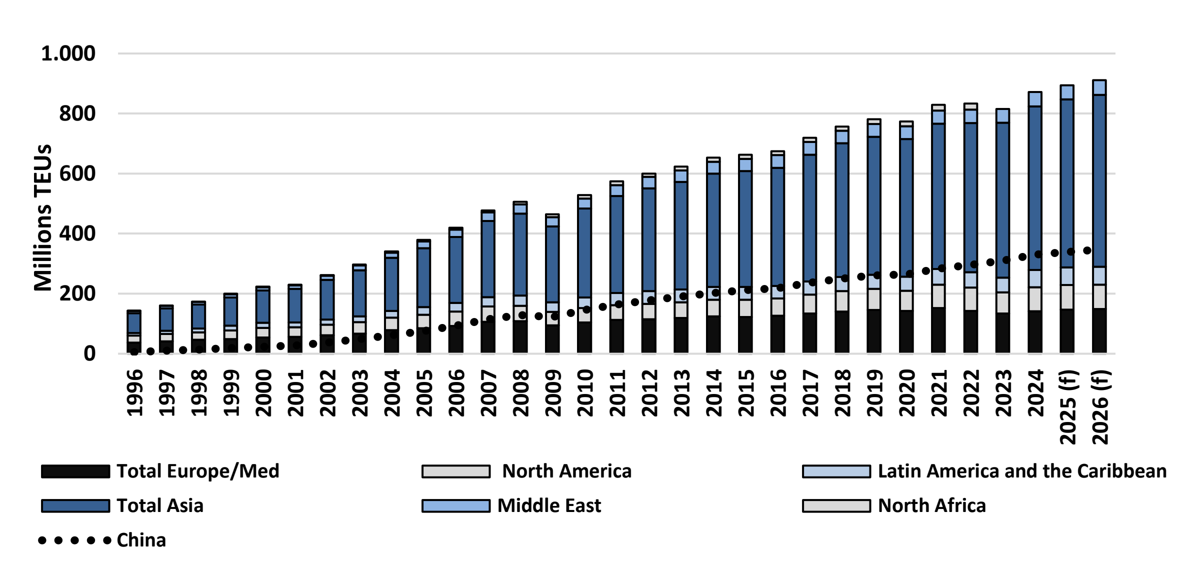
2.1 The Container Liner Shipping World Trade and the Global Fleet Overview

In the maritime industry, containerships were introduced as a revolutionary transportation mode, able to handle general cargo through automation and standardisation processes. These vessels transport various goods in standardised, efficiently stackable containers, utilising cell guides and sometimes onboard cranes for loading and unloading operations. They offer reliable service on fixed schedules and routes across major ports, with sizes ranging from small feeder containerships (up to 3,000 TEUs) to Post-Panamax vessels (+17,000 TEUs), primarily for international trade (Levinson, 2016).

Furthermore, containerisation was successful in the time reduction, and it changed the way that liner companies operated for five reasons: First it inserts the 'door-to-door' services and the logistics operations; second, the business combined into fewer companies, and as a result, the sector became the most concentrated in the shipping activity; third, new port terminals with fewer staff and ships were created; fourth, the core of the business services was through transport, and finally, the tramp ships with containerisable cargo disappeared. Furthermore, one of the most critical decisions for a liner company is whether to charter or purchase a ship. At the beginning of 1990, most of the fleet was owned by the liner companies, which were gradually taken over by different operators, who managed to own almost half the fleet by 2007 (Stopford, 2009).

Figure 2.1 shows the evolution of container trade throughput across different regions from 1996 to 2025 (forecasted). Over this period, international container trade has experienced significant growth, reaching approximately 868 million TEUs in February 2025. This expansion has been primarily driven by Asian economies, where total container throughput rose from around 65 million TEUs in 1996 to over 450 million TEUs by 2024. Notably, China has emerged as the leading contributor to global container trade, with its container throughput increasing from approximately 5 million TEUs in 1996 (representing 3.46% of global trade) to over 250 million TEUs in 2024 (33.76% of the global total). Europe represents the second-largest region, growing from 36 million TEUs in 1996 to approximately 149 million TEUs in 2024, still less than half of China's total, while North America was ranked as the third major region, with container throughput rising from 24 million TEUs to nearly 65 million TEUs over the same period.

Figure 2.1: Global container throughput

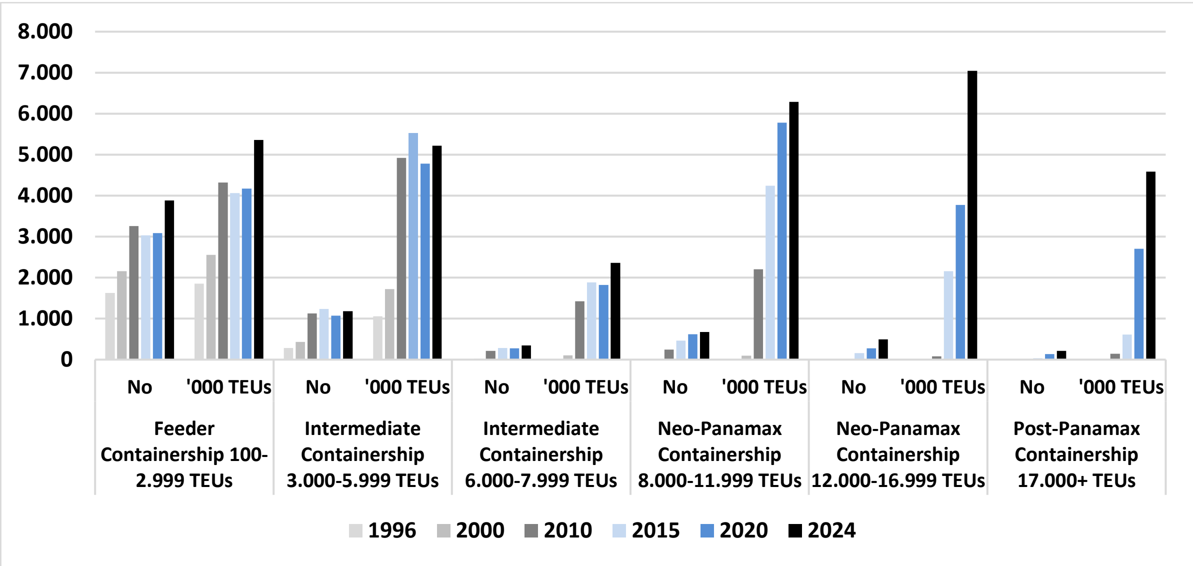


Source: Own compilation based on Clarkson's Research NV (2025)

The growing demand for containerised trade has also influenced the development of the container fleet over time. Figure 2.2 presents an overview of the growth in the number of vessels and their transport capacity from 1996 to 2024, highlighting a steady expansion in both aspects. In 1996, the majority of containerships were 'Feeder' vessels (100–2,999 TEUs), with 1,630 ships and a total capacity of 1.8 million TEUs. By 2024, the number of Feeder vessels increased to 3,879, with a combined capacity of 5.3 million TEUs. The intermediate containerships (3,000–5,999 TEUs) also recorded strong growth, with vessel numbers rising from 281 in 1996 to 1,182 in 2024, while their total capacity shows a nearly fivefold increase, growing from 1.1 million TEUs in 1996 to 5.2 million TEUs in 2024.

After 2008–2010, the container fleet saw notable expansion in the larger size segments, specifically the 'Neo-Panamax' (8,000–11,999 and 12,000–16,999 TEUs) and 'Post-Panamax' (17,000+ TEUs) classes. As of 2024, the capacity of the Neo-Panamax 8,000–11,999 TEU and 12,000–16,999 TEU segments reached 6.28 million and 7.04 million TEUs, respectively, while the 'Post-Panamax' category included 217 vessels, with a total capacity of 4.58 million TEUs. Overall, as of February 2025, the container shipping industry accounted for approximately 16% of the global fleet capacity (Clarksons research, 2025), while the increase in container vessel's size represents the industry's efforts to achieve economies of scale, supported by advances in ship design, and energy efficiency that enable the cost-effective transport of goods (Rau and Spinler, 2016).

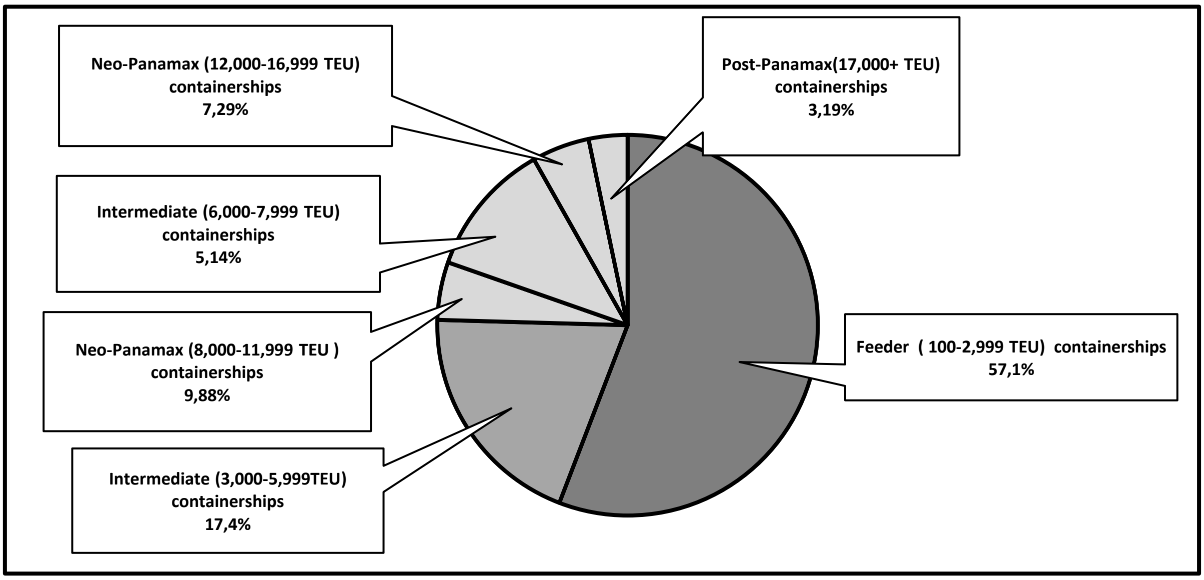
Figure 2.2: Global container fleet development



Source: Own compilation based on Clarkson's Research NV (2025)

As illustrated also in Figure 2.3, by February 2025, feeder containerships between 100–2,999 TEU represented the majority of the global fleet, accounting for 57.1% of all vessels, followed by intermediate containerships of 3,000–5,999 TEU, with a 17.4% share, while the remaining 24% of the fleet consisted of vessels with capacities above 6,000 TEU.

Figure 2.3: *Container fleet contribution in the global market as of February, 2025*

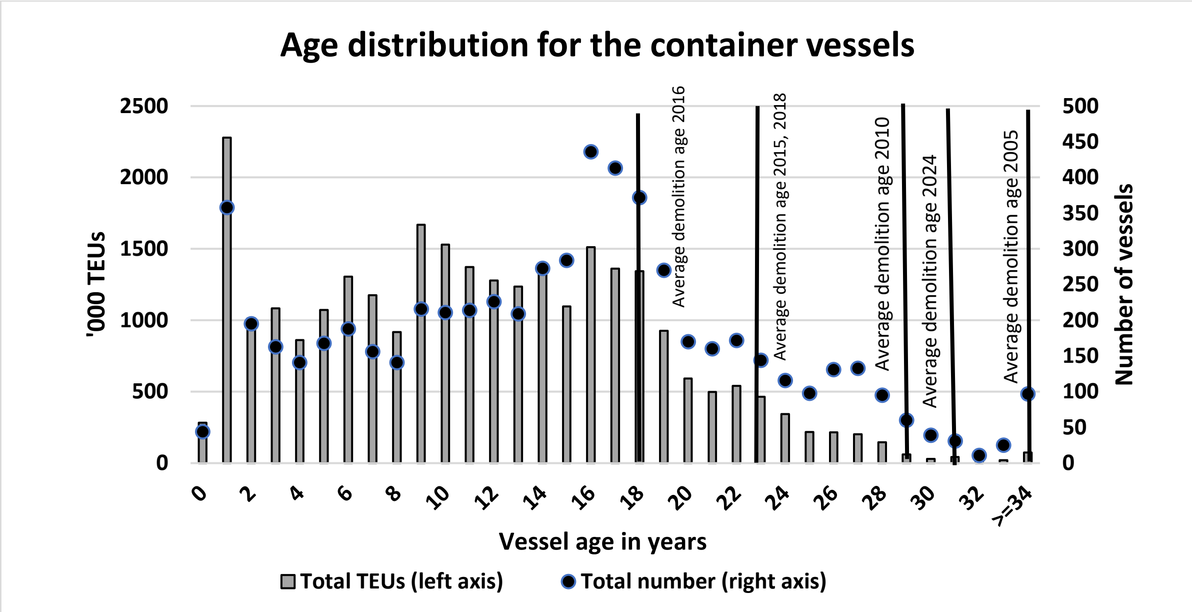


Source: Own compilation based on Clarkson's Research NV (2025)

Similarly, Figure 2.4 shows the age distribution of the containership fleet as of December 2024, categorised by the number of vessels and their total transport capacity, along with the average demolition age across different time periods. It is observed that older containerships exhibit a decrease in transportation capacity, with vessels older than 15 years comprising most of the fleet in terms of ship number, while larger ships are generally younger than 15 years. More specifically, as of February 2025, there were 3,257 vessels over 15 years old (9.7 million TEUs) and 2,903 vessels under 15 years old (18.45 million TEUs), indicating that approximately an additional 10 million TEUs in terms of vessel capacity should be replaced in the following years, especially for vessels that do not comply with the IMO and EU regulations. Additionally, the fleet included 97 vessels older than 34 years, built before 1990, totalling a capacity of 74.000 TEUs, suggesting that some investors continue to operate very old vessels despite their operational inefficiency, and this observation was further reinforced during the huge demand after the COVID-19 period (Clarkson's Research, 2022.; Clarksons research, 2025).

The average demolition age of containerships has also varied over time, reflecting shifts in both market conditions and regulatory pressures. In 2005, the average scrapping age peaked at around 30 years, as older vessels remained economically viable during a period of strong trade growth, particularly driven by China's industrial expansion. In 2016, the average demolition age dropped significantly to around 19 years, marking one of the lowest levels on record. This was primarily driven by a deep market downturn, with historically low freight and charter rates making many older and mid-aged vessels uneconomical to operate, while, in 2016, the expansion of the Panama Canal further accelerated scrapping activity by reducing the demand for 'old Panamax' vessels, many of which were still relatively young (Clarksons research, 2017). By 2018, uncertainty regarding the implementation of IMO and EU decarbonisation regulations had further complicated investment and divestment decisions. Geopolitical disruptions and the complexities introduced by COVID-19 have also impacted the industry, challenging owners' strategic planning, while at the same time, these factors, along with strong freight markets, contributed to a lengthening of service life for older vessels (Clarksons research, 2024). These developments show how evolving economic and regulatory conditions have not only impacted the timing of investment (or divestment) decisions but have also adjusted the overall age profile of the containership fleet.

Figure 2.4: Container vessel age distribution



Source: Own compilation based on Clarkson's Research NV (2025)

Overall, investment decisions within the container shipping sector are primarily impacted by the dynamic interplay among four principal maritime markets: the freight (including time-charter) market, the sale and purchase (S&P) market, the newbuilding market, and the demolition market (Stopford, 2009). These markets constitute an integrated system in which developments and actions in one segment often have immediate effects on the other markets. Collectively, they enable the circulation of cash flows, drive the adjustment of asset values, and provide the mechanisms through which shipowners respond strategically to market pressures, such as regulatory interventions or technological advancements.

In this context, the following part of this research examines the container liner shipping industry by providing a more descriptive analysis of the three pivotal markets in which shipowners operate and make investment decisions. The primary objective of the essay is to observe how investment decisions formed the industry's outlook over the past two decades, with the aim of providing insights concerning the greening efforts towards decarbonisation.

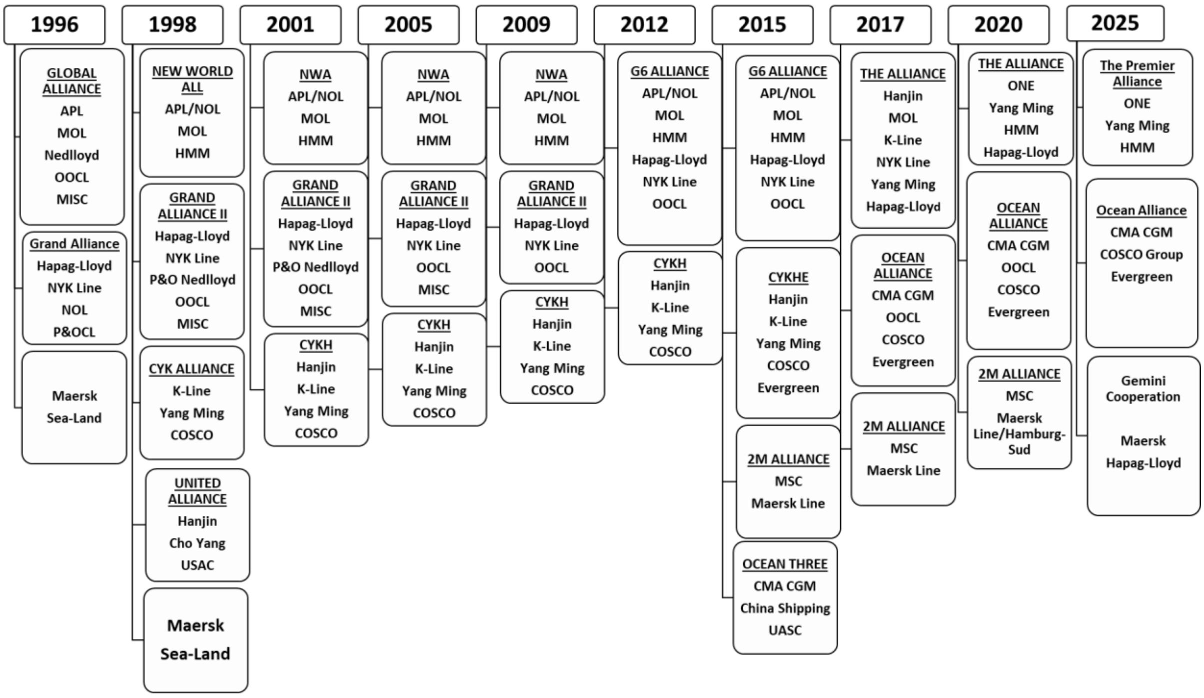
The remainder of the essay is structured as follows. Section 2.2 provides an overview of the leading container shipping companies, the evolution of market concentration, and the deployed fleet capacity of the top 10 shipping operators. Section 2.3 examines the three principal shipping markets, namely the freight and time-charter market (section 2.3.1), the second-hand market (section 2.3.2), and the newbuilding market (section 2.3.3), analysing their respective dynamics and relevance to investment behaviour in the container shipping industry. Section 2.4 delves into the evolving regulatory framework, with particular emphasis on the decarbonisation initiatives introduced by the International Maritime Organisation (IMO) and the European Union (EU). In section 2.4.2, special attention is given to the development and implications of alternative fuel adoption in response to these regulatory pressures. Finally, Section 2.5 concludes the study by summarising the main findings of the research and provides 3 scenarios based on the current market observations.

2.2 Market Concentration and Container Shipping Operators

In response to persistent pricing pressures and volatility in global trade, container liner companies have increasingly turned to strategic corporate and operational collaborations, particularly through mergers and acquisitions (M&A), slot chartering agreements (SCA), vessel-sharing agreements (VSA), and strategic alliances. Slot chartering agreements (SCA) involve partners buying and selling a defined allocation (slot) on a vessel for a predetermined time and price. Vessel-sharing agreements allow a limited number of shipping companies to operate a liner service along a specified route with a set number of vessels, where the capacity allocation can vary from port to port. Likewise, alliances and M&A are strategies employed by shipping lines to achieve economies of scale, access new markets, enhance global reach, improve fleet deployment, and spread investment risks, while also enabling carriers to strengthen their competitive position, optimise operational efficiency, and better respond to market volatility and regulatory challenges (Ghorbani et al., 2022).

As illustrated in Figure 2.5, by 2025, the global alliance structure is expected to shift significantly, with the Ocean Alliance remaining unchanged in membership and continuing to represent approximately 29% of global container shipping capacity. The 2M Alliance, however, is expected to dissolve, with Maersk forming a new alliance, namely the Gemini Cooperation, with Hapag-Lloyd, accounting for roughly 22% of market share. At the same time, MSC is expected to operate independently, while the Alliance will be restructured and renamed as the Premier Alliance, comprising ONE, Yang Ming, and HMM, and will represent an estimated 12% of market capacity. In addition, independent operators, such as MSC and ZIM, along with other niche carriers, are forecasted to constitute approximately 37% of the global container shipping market (Frederick, 2025). The significant restructuring of global container shipping alliances in 2025 is expected to have a direct impact on fleet investment decisions, particularly regarding green technologies and vessel upgrades. As alliances realign, such as the formation of the Gemini Cooperation between Maersk and Hapag-Lloyd, the creation of the Premier Alliance by ONE, Yang Ming, and HMM, and the continued dominance of the Ocean Alliance, there is increased competitive pressure among member lines to maintain service compatibility and operational alignment across shared networks. For example, when a major carrier within an alliance invests in greener ships, such as dual-fuel or LNG-powered vessels, partner lines often experience pressure to follow this carrier in order to maintain service compatibility and operational alignment within the shared network agreement (Notteboom, 2024; Shang et al., 2024).

Figure 2.5: *Alliances in the container liner shipping as of February, 2025*



Source: Own compilation based on Notteboom (2024) and Shang et al. (2024)

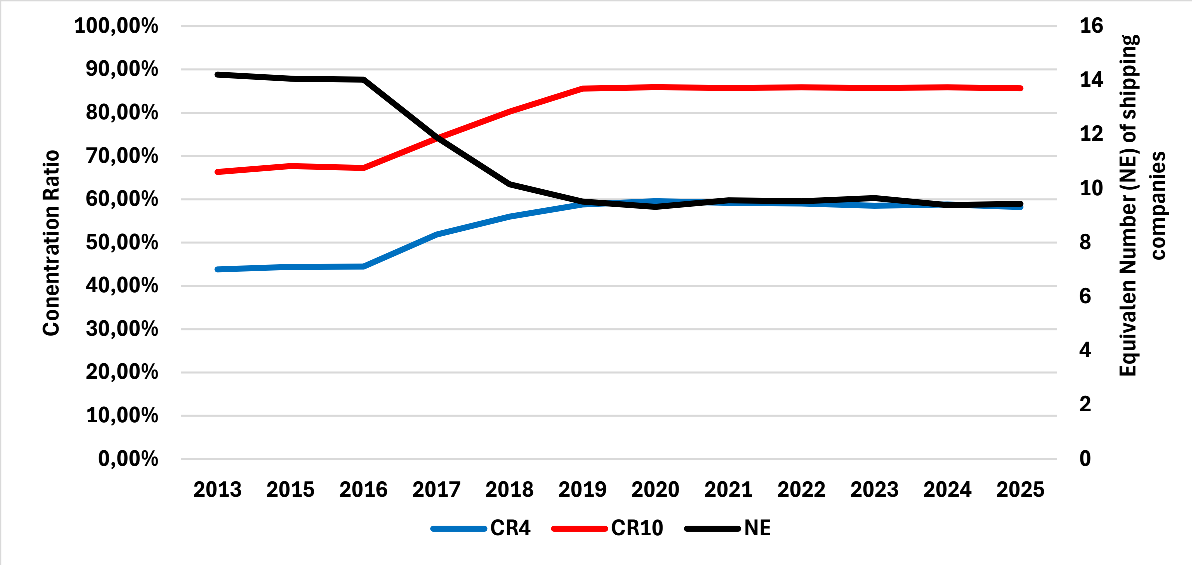
In this context, it is important to distinguish the roles of shipping operators and shipowners. Operators, often liner companies, manage the deployment of vessels on scheduled services through organised networks and alliances, providing transport capacity to shippers. Conversely, shipowners are the legal owners of the vessels and may also include individual investors, financial leasing firms, and banks. These investors finance newbuilding orders and lease their ships to operators under time charter agreements. From the perspective of vessel ordering, shipowners play the primary role in the investment decisions, as they determine the timing, scale, and technological profile of the ship. At the same time, major operators in the container shipping sector frequently act as shipowners by placing newbuilding orders directly to secure capacity. (Pagonis and Pentheroudakis, 2019).

Following the methodology of Sys (2010), who assessed concentration in container liner shipping using structural indicators (CRn, HHI, NE) and the Hymer–Pashigian Instability Index to capture market share dynamics in the container liner sector, Figure 2.6 presents the concentration ratios (CR4, CR10)[4] and the Number Equivalent (NE)[5] as measures of structural concentration in the container shipping market. These indicators were calculated using fleet capacity data (measured in TEU) of the top 100 operating carriers, with CRn derived from the cumulative market share of the n largest firms, the HHI obtained by summing the squared market shares, and the NE computed as its inverse to reflect the effective number of competitors. More specifically, between 2013 and 2025, the global container shipping market has experienced a clear trend of increasing concentration, as reflected in both traditional concentration ratios and structural indices. The CR4 rose from 43.8% in 2013 to over 58% by 2025, while the CR10 exceeded 85% in 2025, indicating that the top 10 firms dominate most of the market operational capacity. This trend is further reinforced by the decrease in the number equivalent (NE) from 14.2 in 2013 to 9.4 in 2025, suggesting a significant structural consolidation. The NE interprets the observed concentration as equivalent to a market composed of fewer than 10 equally-sized firms in 2025, compared to over 14 in 2013, suggesting that the investment behaviour from the top 10 firms directly forms the overall trajectory of fleet development, green technology adoption, and market competition in the container shipping industry (Sys, 2009, 2010; Ghorbani et al., 2022).

[4] The CR4 (Four-Firm Concentration Ratio) and CR10 (Ten-Firm Concentration Ratio) represent the combined market share of the four and ten largest companies in the market, respectively. It is commonly used to assess the degree of concentration at the top end of an industry.

[5] The Number Equivalent (NE) is an inverse measure of concentration derived from the Herfindahl-Hirschman Index (HHI), calculated as 10,000 divided by the HHI. It indicates the number of equally sized firms that would generate the same level of market concentration, offering a more intuitive interpretation of structural dominance.

Figure 2.6: Evolution of Market Concentration in Container Shipping (2013–2025)



Source: Own compilation based on Sys (2010) and Alphaliner (2025)

Similarly, Figure 2.7 offers an insightful overview of the top 10 operators and shows the evolution of owned and chartered fleet capacity among leading container carriers from 2013 to 2025, grouped by alliance affiliation as of February 2025. Maersk, a core member of the Gemini Cooperation, expanded its owned fleet from 1.30 million TEU (2013) to 2.55 million TEUs (2025), while its chartered capacity increased from 1.28 to 1.86 million TEU, showing a clear preference for asset ownership. Hapag-Lloyd followed a similar pattern, with owned tonnage growing from 324,000 TEU (2013) to 1.34 million TEU (2025), and chartered tonnage rising from 308,000 to 987,000 TEU.

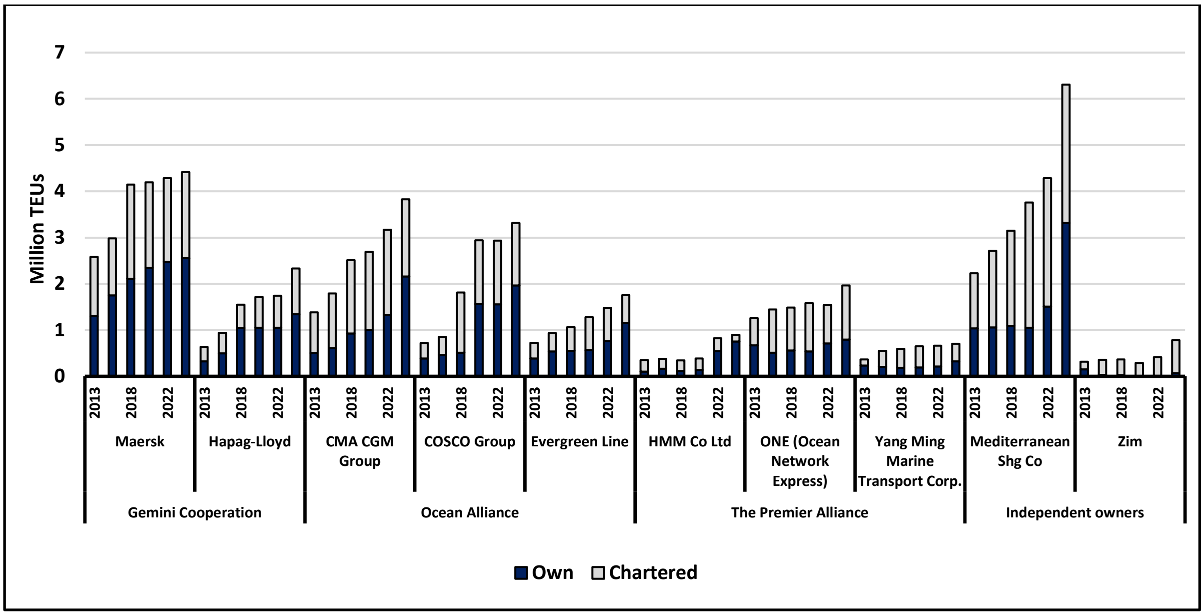
Within the Ocean Alliance, COSCO expanded rapidly, increasing both its owned and chartered fleet between 2013 and 2025, where the owned capacity rose from 384,000 TEU (2013) to nearly 2.0 million TEU (2025), while chartered capacity grew from 332,000 to 1.35 million TEU. CMA CGM also expanded its owned fleet from 503,000 TEU (2013) to 2.16 million TEU (2025), while chartered capacity rose from 882,000 to 1.67 million TEU during that period. Evergreen also strengthened its ownership, increasing its owned capacity from 382,000 TEU

(2013) to 1.15 million TEU (2025), while chartered tonnage grew more modestly from 341,000 to 606,000 TEU.

In addition, the Premier Alliance members showed more varied strategies. HMM's owned fleet grew from just 101,000 TEU (2013) to 752,000 TEU (2025), while chartered capacity nearly tripled from 251,000 to 606,000 TEU. ONE (Ocean Network Express), modestly increased its owned fleet from 668,000 TEU (2013) to 792,000 TEU (2025), but significantly boosted its chartered tonnage from 591,000 in 2013 to 1.17 million TEU in 2025, highlighting a growing preference for external capacity over asset-heavy investment. Yang Ming, another member of the Premier Alliance group, showed limited growth in both segments, reaching 711,000 TEU in owned and 1.17 million TEU in chartered capacity by 2025.

Lastly, among independent carriers, Mediterranean Shipping Company (MSC) showed the biggest growth in fleet size during the period of the analysis, with its owned capacity rising from 1.03 million TEU (2013) to 3.32 million TEU (2025), and chartered capacity increasing from 1.19 million to 2.99 million TEU, making it the largest carrier by total operating capacity. In contrast, ZIM maintained an asset-light strategy, with owned capacity declining from 148,000 TEU (2013) to just 66,000 TEU (2025), while chartered capacity surged from 170,000 to 714,000 TEU.

Figure 2.7: Top 10 container operators' deployed fleet



Source: Own compilation based on Alphaliner (2025)

Overall, it is evident that over the last years, the liner shipping industry has seen significant M&A activity, influencing the market structure and increasing the concentration of control capacity, raising additional concerns regarding market concentration and the potential for oligopolistic behavior (Sys, 2009; Ghorbani et al., 2022). Such structural shifts are particularly relevant in the context of investment dynamics, as highly concentrated markets tend to amplify the influence of first-mover strategies. In particular, early adoption of green technologies by leading carriers, such as investments in alternative-fuel propulsion systems or energy-efficient ship designs, often establishes new industry standards. As a result, investment responses across the container shipping industry tend to be asynchronous, reinforcing the dominant position of large carriers in taking investment actions towards innovation and decarbonisation (Shang et al., 2024).

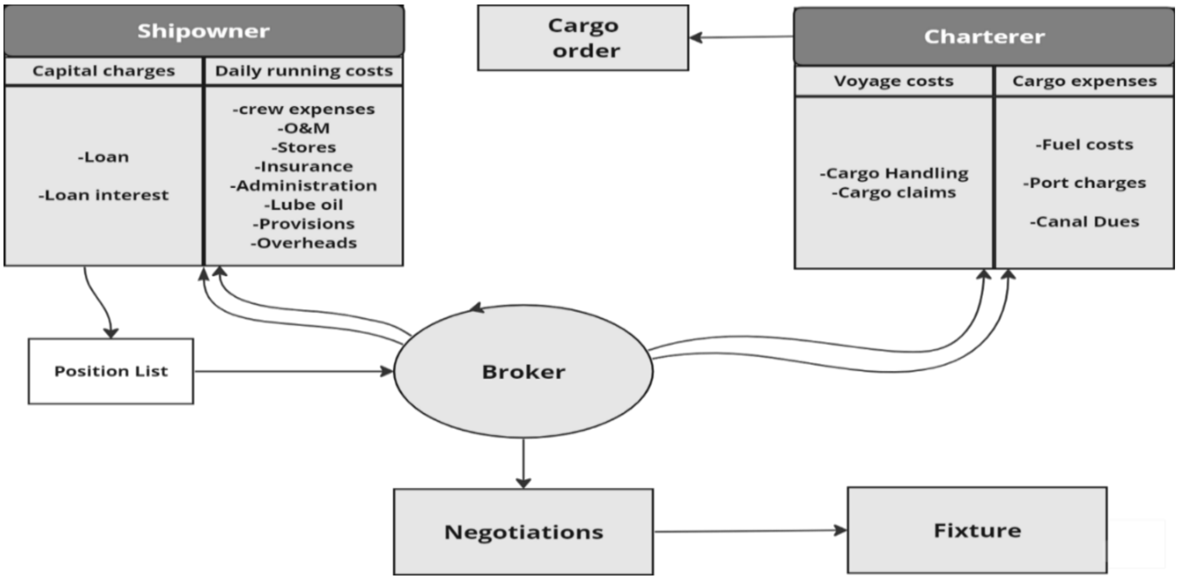
2.3 The Freight, Second-hand, and Newbuilding Markets

The container shipping industry operates through three interconnected markets: the freight market, the second-hand (sale and purchase) market, and the newbuilding market, which collectively inform both the operational and strategic investment decisions of shipowners and operators (Stopford, 2009). Each of these markets plays a distinct role in the container liner shipping industry, offering advantages and challenges for shipping investors and shipowners, all of them impacted by decarbonisation pressures.

2.3.1 The Freight Market

The freight market involves different segments for various ship types, each operating in different regions and locations. Transactions within the container freight market primarily occur in freight contracts and time charters. In a freight contract, the charterer secures transportation from the shipowner at a fixed rate, either under Freight All Kinds (FAK) for any good or at Commodity Box Rate (CBR), with the shipowner handling the transport logistics (Stopford, 2009). Conversely, in a time charter, the ship is chartered daily, and the charterer manages the transport themselves, with the voyage costs and the cargo expenses, such as fuel costs, port charges, etc., to be on the charterer's account. The process of chartering a ship for transport involves shipowners offering their vessels for hire, charterers seeking transportation for their cargo, and brokers who facilitate these transactions (Pagonis and Pentheroudakis, 2019).

Figure 2.8: Negotiation process in the time charter market. Source: Author's compilation based on Pagonis and Pentheroudakis (2019)



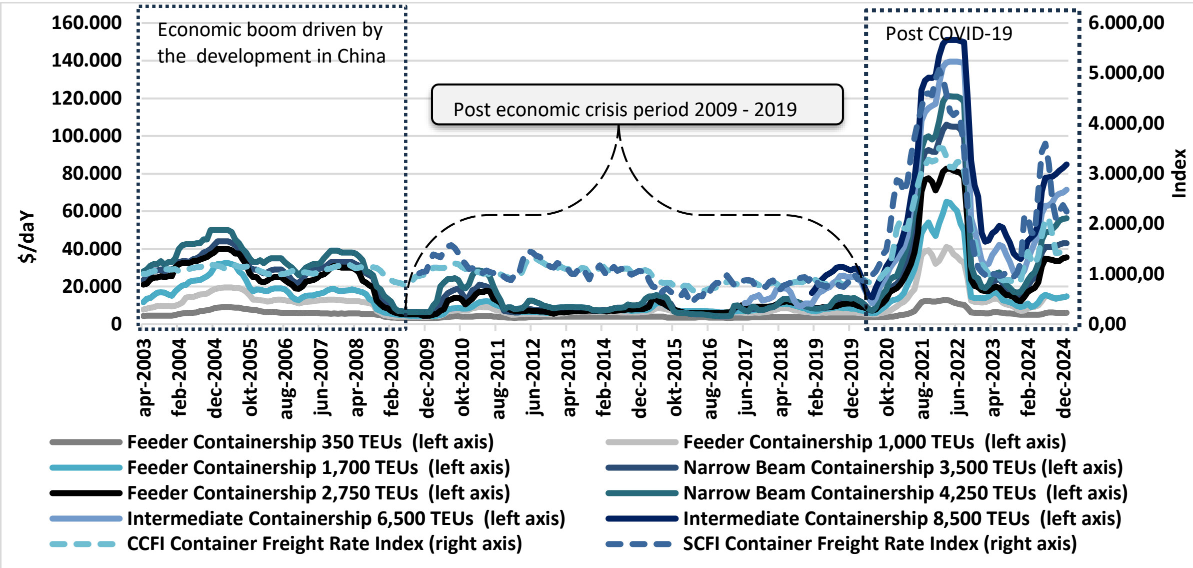
Source: Own compilation based on Pagonis and Pentheroudakis (2019)

The time-charter market plays a key role in generating revenue and often influences investment decisions, as vessels with lower emissions and better fuel efficiency are more likely to attract long-term contracts and premium rates (Agnolucci et al., 2014; Adland et al., 2017). Additionally, for shipowners, the stable cash flows provided by time-charter contracts are vital for maintenance and regulatory capital expenditures, especially in the context of increasing emission constraints and investments in fuel efficiency technologies, while such improvements can lead to extended contract durations and potentially higher time-charter rates (Adland et al., 2017). Furthermore, entering a time-charter contract can be regarded as an investment decision, as shipowners allocate their assets for a fixed period in return for expected revenues, and may also act as charterers themselves, hiring in vessels from other owners to expand their fleet capacity or to cover short-term demand without committing to newbuilding or second-hand acquisitions.

Figure 2.9, illustrates the time charter rates for different vessel sizes (in $/day), the China Container Freight Index, and the Shanghai Container Freight Index from March 2003 to January 2025. The China Container Freight Index (CCFI) and the Shanghai Container Freight Index (SCFI) illustrate the evolution of container freight rates, with the CCFI reflecting average contractual rates across multiple routes from Chinese ports and the SCFI capturing spot market rates on major export containerised trades from Shanghai. As can be seen, the dynamics of time charter rates in the container liner shipping industry have been impacted by global economic changes, market conditions, and regulatory shifts. Between 2004 and 2008, during China's economic development, freight rates were relatively stable compared to the more volatile time charter rates, reflecting fluctuations in vessel demand. In 2009, the global financial crisis led to increased volatility in freight rates, and this situation was intensified after the abolition of conferences in the liner industry that previously acted as a stabilising price mechanism (Kalgora and Christian, 2016). A temporary time-charter rate recovery in 2010 was quickly offset by market imbalances, with equilibrium returning only post-2018, a period that also marked modest advances in eco-friendly shipping technologies (UNCTAD, 2023).

From 2020 onward, the container shipping industry experienced a historic surge in time charter rates, driven by the post-COVID-19 supply chain recovery and limited availability of vessel tonnage. By September 2020, the time charter rate index had risen by 54% compared to the beginning of the same year. This upward trend continued into 2021, reflecting intense demand and tight vessel supply across major trade routes. However, in 2022, both freight and charter rates began to decline, largely due to economic downturn, higher inflation, and elevated retail inventory levels. By the end of August 2022, the time charter rate index had dropped by 60% from its peak, but it remained significantly above pre-COVID levels, a profitability margin that enabled shipowners to accumulate substantial cash revenues (Clarkson's Research, 2023). The profitability experienced by container shipping companies during the post-pandemic period resulted in a significant accumulation of cash reserves, often referred to as a "cash bubble", with a substantial portion of these earnings reinvested in fleet renewal, with a particular focus on ordering new, environmentally friendly vessels. In 2024 alone, global contracting reached its highest level since 2007, with containerships accounting for nearly half of Gross Tonnage (GT) ordered, totalling 62.2 million GT, with 4.4 million TEU ordered in 2024, breaking the previous record of 4.3 million TEU set in 2021 (Clarksons research, 2025).

Figure 2.9: Time charter rates, CCFI and SCFI index for containers over the period 2003 – 2024



Source: Own compilation based on Clarkson's Research NV (2025)

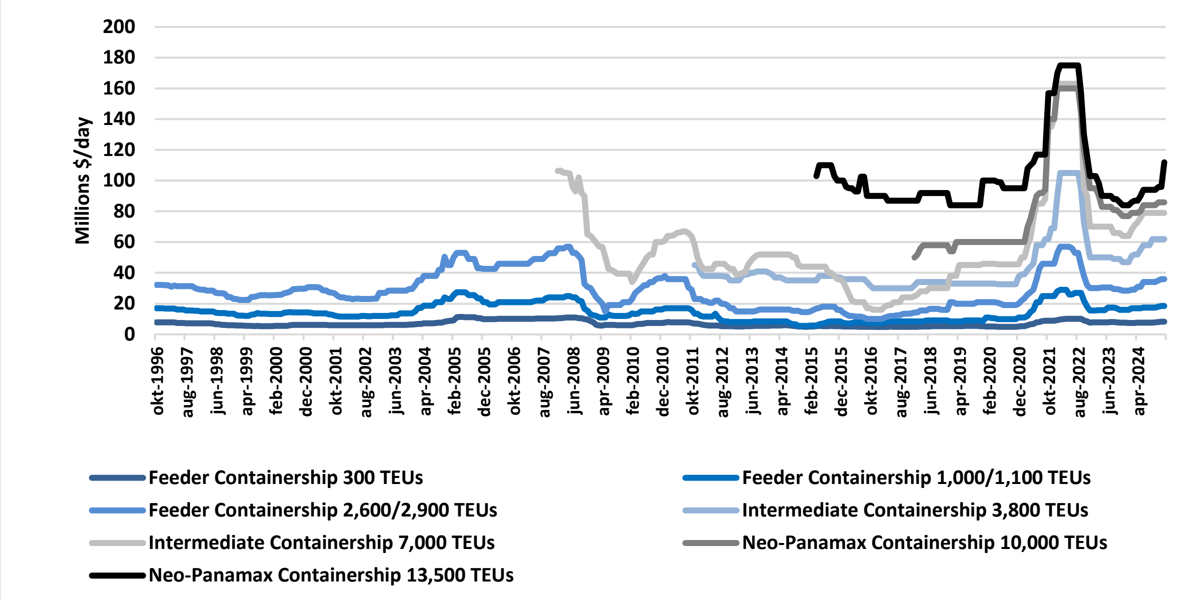
Overall, the container shipping market has experienced considerable fluctuations in both freight and time-charter rates, shaped by macroeconomic shifts, supply chain disruptions, and regulatory standards. Recent regulatory developments at both the EU and IMO levels have intensified these dynamics, particularly by incentivising the deployment of modern, fuel-efficient vessels to minimise compliance costs and reduce exposure to emissions penalties (Clarksons research, 2024). Furthermore, time-charter rates remain highly sensitive to global trade patterns, with larger ships consistently achieving higher rates due to their larger capacity and cost-efficiency, derived from economies of scale (Van Hassel et al., 2016).

2.3.2 The Sales and Purchase Market

The sales and purchase market is the market where the participants are commonly shippers, shipowners, and investors who also trade in the other shipping market sectors (Stopford, 2009). When a shipowner wants to sell a ship, he/she come into the market with a ship for sale. On the other hand, there is a potential buyer who wants to purchase a ship when it is suitable for his trades or when he is a new investor who wants to enter the market. The sales and purchase market allows for flexible, timing-based investment strategies as asset values fluctuate with market cycles and regulatory developments and provides direct capacity access in the market. It also reduces the barriers to entering the market due to lower capital commitment compared to the newbuilding market, where investment costs typically are higher and delivery times are longer, as a vessel may require up to 2–3 years to be built (Stopford, 2009).

This part of the analysis is concentrated on the formation of the second-hand prices and the sales numbers for different container ship sizes across October 1996 to February 2025. Figure 2.10 *pre*sents the evolution of the 5-year ships' second-hand prices across different container ship sizes from 1996 to February 2025. It can be observed that as vessel size increases, second-hand prices also rise and exhibit higher volatility, especially in periods characterized by intense demand and market fluctuations. Larger ships face greater volatility because their value is tied to fewer available vessels in each size class, making them more sensitive to shifts in demand and freight rate cycles (Kalgora and Christian, 2016). Furthermore, during the market boom of 2004 – 2008, there was a significant increase in container vessel second-hand prices, especially for 3,800 TEUs, driven by shipowners' demand for immediate vessel capacity (Clarksons research, 2008), while a similar observation appeared after the supply chain disruption caused by COVID-19 (Clarksons research, 2022).

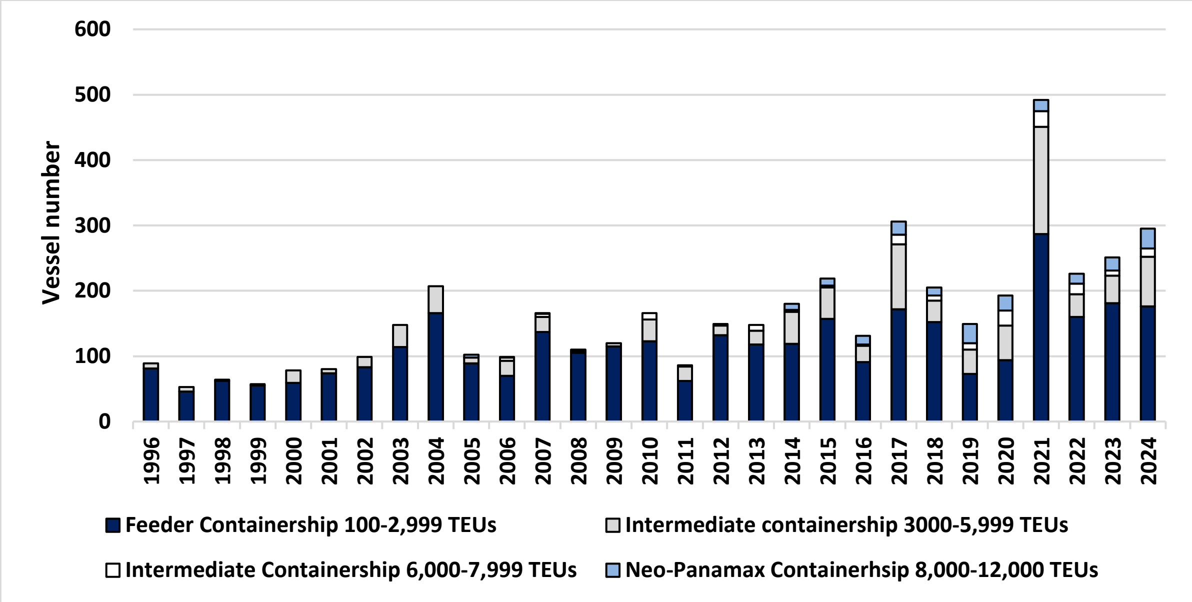
Figure 2.10: Second-hand prices across different container vessels prices



Source: Own compilation based on Clarkson's Research NV (2025)

Figure 2.11 shows the annual sales of containerships across four size categories from 1996 to 2024, including Feeder Containerships (100–2,999 TEUs), Intermediate Containerships (3,000–5,999 TEUs and 6,000–7,999 TEUs), and Neo-Panamax Containerships (8,000–12,000 TEUs). Feeder containerships consistently dominate the second-hand market, with significant peaks in 2004 (166 vessels), 2017 (172 vessels), and a sharp surge in 2021 (287 vessels). The 3,000–5,999 TEU intermediate segment shows a steady upward trend, with major increases in 2017 (99 ships) and 2021 (164 ships), reflecting growing demand for mid-sized vessels. Sales of 6,000–7,999 TEU vessels remain minimal until 2010 but gradually increase thereafter, peaking at 24 containerships in 2021. Neo-Panamax containerships began to appear in the market from 2005, with a generally upward trend that concluded with a record 30 vessels sold in 2024.

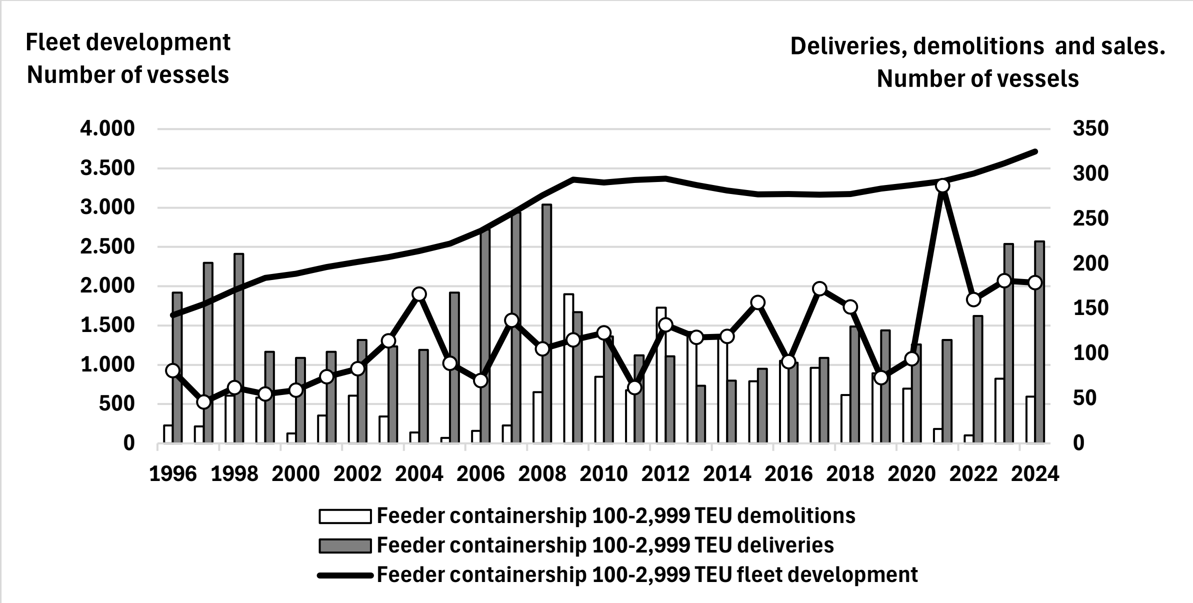
Figure 2.11: Containership sales volumes across different vessel sizes



Source: Own compilation based on Clarkson's Research NV (2025)

Despite the rise in sales of larger vessels, the second-hand market remains predominantly composed of smaller and intermediate containerships, indicating that larger container vessels are typically held for longer periods or change ownership less frequently. Building on this observation, Figure 2.12 present in more detail the fleet development of the feeder and intermediate containerships. As can be observed, from 1996 to 2008, the feeder containership market experienced rapid development, with 3,280 vessels operating in 2009. However, from 2009 to 2017, the fleet experienced a 10% reduction, as many vessels were sold for scrapping. More specifically, the number of demolished containerships in those years was 934, resulting in the fleet falling to 2,932 ships by 2017. By 2024, the number of Feeder vessels had increased to 3,879 ships, with a noticeable peak in vessel transactions in 2021, which included 287 containerships.

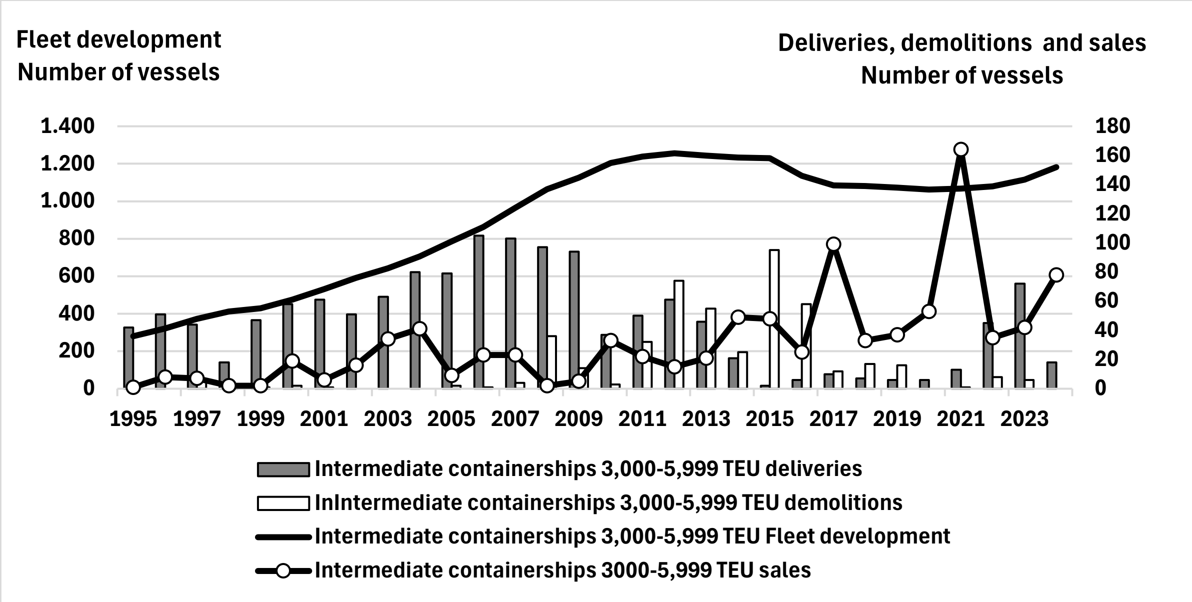
Figure 2.12: Feeder containerships (100-2,999 TEU) fleet development



Source: Own compilation based on Clarkson's Research NV (2025)

At the same time, Intermediate containerships (3,000–5,999 TEU) presented a smoother and more gradual development, reaching 1,238 vessels in 2015 (Figure 2.13). However, from 2013, the old vessels started to be demolished, reducing the fleet to 1,066 intermediate containerships in 2021, and rising to 1,182 in 2024. A noticeable peak in the sales activity for intermediate containerships was observed in 2021, with 164 vessel transactions.

Figure 2.13: Intermediate containerships (3,000-5,999 TEU) fleet development



Source: Own compilation based on Clarkson's Research NV (2025)

Overall, several notable trends can be distinguished in the containership second-hand market. First, the second-hand market is highly sensitive to broader market conditions and shaped by the expectations of shipowners and investors. Vessel size preferences vary across time, with the majority of transactions concentrated in feeder and intermediate containerships, reflecting changing economic and operational considerations. For example, a surge in sales of small to medium-sized containerships was observed between 2002 and 2004, as rising market demand linked to China's economic expansion pushed up asset values and created profitable opportunities for shipowners to sell vessels. This momentum slowed in 2005 and 2006 as many shipowners chose to keep their vessels in operation through time-charter or spot market contracts, temporarily reducing second-hand sales. As overall market activity remained strong, vessels released from charter agreements re-entered the second-hand market, leading to increased sales volumes and rising prices, especially for feeder and intermediate vessels in 2006–2007 (Clarksons research, 2010). Similar dynamics emerged after the financial crisis (2010) and again in 2017, 2019, and 2021 (Clarkson's Research, 2023).

The period from 2020 to 2022 marked an exceptionally active phase for the industry, impacted by global supply chain disruptions, tightening environmental regulations from the IMO and EU decarbonisation targets, and geopolitical uncertainty. During this period, many shipowners temporarily idled vessels for retrofitting, maintenance, or repair, tightening fleet availability and contributing to a sharp rebound in charter demand, particularly in the time-charter segment (Clarkson's Research, 2023). Lastly, it was also observed that the second-hand market remains predominantly composed of smaller feeder containerships.

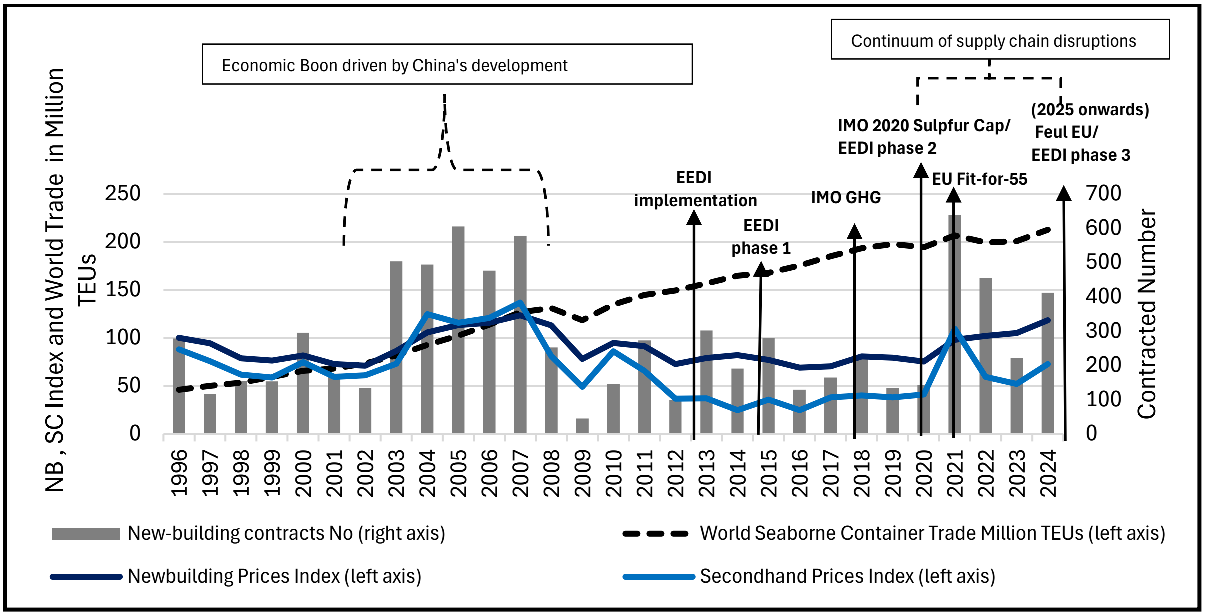
2.3.3 The Newbuilding Market

The new-building market, one of the core maritime markets identified by Stopford (2009), is where shipowners place orders for newly constructed vessels. These new building orders often reflect the need for additional capacity, specific operational capabilities, regulatory compliance, such as decarbonisation requirements, or the adoption of advanced technologies like alternative fuels and advanced technologies, which are not typically available in the second-hand market. Negotiations between shipowners and shipyards involve three primary aspects: 1) vessel specifications, 2) contract pricing, and 3) construction processes and timelines (typically ranging from 1 - 3 years). Given these time lags, ordering decisions in the new-building market are highly sensitive to both current market conditions and expectations about future freight rates, regulatory developments, and technological change. Furthermore, the shipbuilding industry is both capital-intensive and cyclical (Ferrari et al., 2018). Traditionally, key drivers influencing shipowners' investment decisions in the newbuilding market have included freight market conditions, second-hand vessel prices, and overall market sentiment, while vessel technical specifications such as operational efficiency, compliance with regulatory measures, and specialised vessel requirements also played a significant role (Stopford, 2009). Jiang et al. (2013) indicated that while China has historically maintained a cost advantage over the Republic of Korea and Japan, rising labour costs and shipping equipment expenses could erode this edge. China's state-backed policies have also driven its shipbuilding market share from under 5% in 1999 to over 50% in 2023, distorting competition, while US policymakers are considering measures such as port fees on Chinese-built vessels to counteract these effects, reflecting broader economic and security concerns in the maritime industry (USTR, 2025).

As illustrated in Figure 2.14, between 1996 and 2024, the containership market experienced steady growth in world seaborne container trade, rising significantly from 46.0 million TEU in 1996 to an estimated 212.6 million TEU in 2024. Historically, investment decisions, as reflected in newbuilding contracts, have closely followed market conditions, including trade volume, newbuilding prices, and secondhand vessel values. Contracting activity peaked during periods of strong market conditions associated with China's economic growth, with 605 contracts totalling 1.63 million TEUs in 2005, and 578 contracts accounting for 3.34 million TEUs in 2007, reflecting a shift toward larger-capacity vessels. Conversely, during economic downturns or periods of weak market sentiment, such as the economic and financial crisis in 2009, new vessel orders sharply declined due to reduced demand and excess ship supply.

In addition, over the last decade, the shipping industry has been adopting advanced technologies, such as exhaust gas cleaning systems (scrubbers), to reduce sulfur oxides and eco-vessel designs to improve energy efficiency, in order to meet the IMO and EU regulatory and environmental challenges. To this extent, and as will be discussed later in Essay 2.4.2, alternative fuels, including liquefied natural gas (LNG), methanol, ammonia, hydrogen, and other synthetic fuels, have been introduced as promising pathways toward decarbonisation (Balcombe et al., 2019; Lee and Nam, 2017a; Wan et al., 2018; Al-Enazi et al., 2021; Foretich et al., 2021). These technological requirements have increased upfront costs and have raised concerns about the long-term viability of older technologies. As a result, shipowners delayed orders, leading to greater volatility in new-building activity between 2016 and 2021, with orders fluctuating between a low of 129 contracts of 316,034 TEUs in 2016 and a sharp rebound to 638 contracts of 4.53 million TEUs in 2021 during the post-pandemic market recovery (Clarksons research, 2022).

Figure 2.14: World Container Trade Growth and Containership Orderbook Dynamics over the period 1996 – 2024

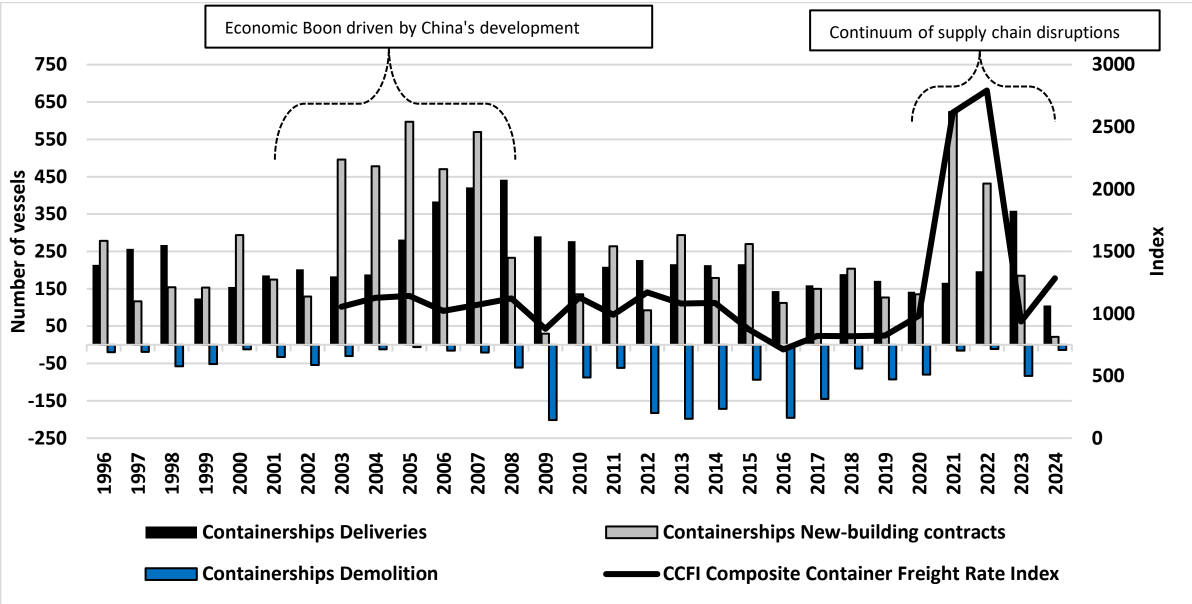


Source: Own compilation based on Clarkson's Research NV (2025)

Furthermore, it is distinguished that while newbuilding prices generally remain above second-hand levels, certain market conditions, particularly when freight markets are strong and newbuilding delivery times are long, approximately up to 1-3 years, have led to temporary reversals. For example, during the 2004–2008 economic boom, strong freight earnings drove high demand for immediate vessel capacity, with second-hand prices surging beyond new building prices, reflecting the urgency for deployable tonnage. A similar pattern re-emerged between 2020 and 2022, as demand rebounded in 2021 following the COVID-19 restrictions, prompting shipowners to secure capacity in the second-hand market (Clarksons Research, 2021).

The shipbuilding market cyclicality for the container liner shipping industry can be seen in Figure 2.15. It can be noticed that during periods characterised by high demand, as happened during the period 2003 – 2008, investors were placing orders for new vessels that came into the market after 2-3 years, while at the same time, the choice to remove the vessel for scrapping remained at low levels. During that period, the contracted orderbook reached 2,611 containerships of 10 million TEUs, while the demolition number was only 85 containerships totalling 85,000 TEUs. Similarly, from 2021 to 2024, the total order book comprised 1,731 containerships with a capacity of 13.23 million TEUs, while the demolition market accounted for 166 vessels with a capacity of 184,000 TEUs. On the contrary, the largest fleet removal was reported in 2016, with 196 ships totaling 657,000 TEUs. In contrast, the reduction in fleet capacity reached 375,000 TEUs in 2009, involving 202 containerships.

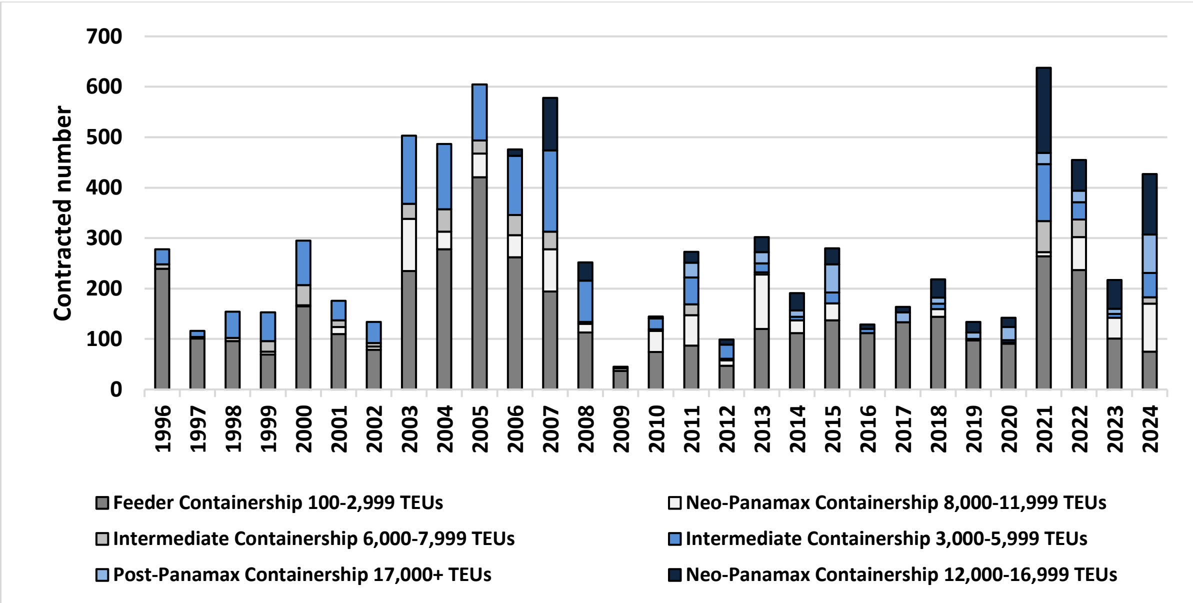
Figure 2.15: Container new building contracts, vessel deliveries, and demolitions



Source: Own compilation based on Clarkson's Research NV (2025)

Figure 2.16 presents a detailed breakdown of containership newbuilding contracting activity by vessel size between 1996 and 2024. The period between 2003 and 2008 marked a significant surge in new building activity, particularly for feeder containerships (100–2,999 TEUs), which recorded 1,588 contracts. Intermediate containerships (3,000–5,999 TEUs) also experienced substantial growth in this period, with 714 contracts, followed by Neo-Panamax containerships (8,000–11,999 TEUs), which reached 328 contracts, while the segment for intermediate containerships (6,000–7,999 TEUs) accounted for 215 contracts. A notable resurgence in contracting activity was observed in the period following the COVID-19 pandemic, particularly between 2021 and 2024, with Neo-Panamax containerships (12,000–16,999 TEUs) emerging as the most contracted segment, with 407 vessels ordered. This was followed by Post-Panamax containerships (17,000+ TEUs), which recorded 131 contracts, and feeder containerships (100–2,999 TEUs) with 677 contracts. Additionally, Neo-Panamax containerships (8,000–11,999 TEUs) reached 209 new orders, while intermediate containerships in the 3,000–5,999 TEU and 6,000–7,999 TEU categories registered 203 and 144 new-building contracts, respectively.

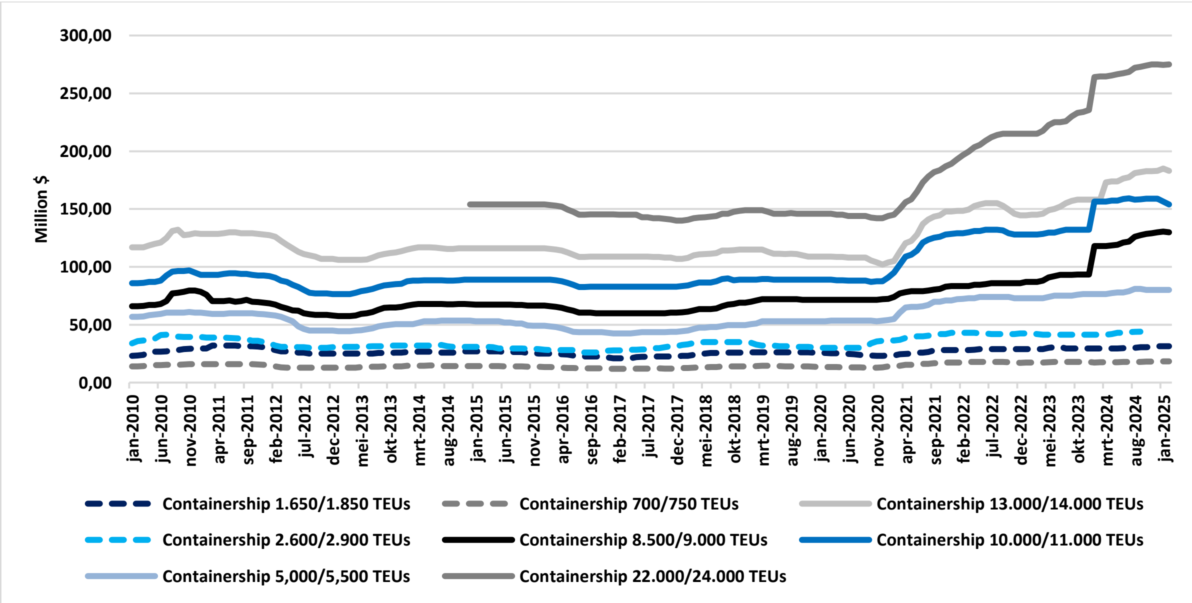
Figure 2.16: The historical contracted number for different container vessel sizes



Source: Own compilation based on Clarkson's Research NV (2025)

Lastly, Figure 2.17 provides the new building prices across different container vessel sizes from October 1996 to February 2025. As seen, the vessel's size is the major contributor to the formation of the new building prices, with bigger ships requiring higher capital investments than smaller ones. Moreover, new-building prices are also determined by standardised shipyards' capacities, creating market competition and increasing prices. This trend was especially evident for the Neo-Panamax (22,000 – 24,000 TEUs) containerships during the period 2020 – 2023, with their prices reaching approximately 264$ million in 2023, a rise of 81.16% from 2020. Similarly, the demand for definite vessel technological specifications or sizes also creates competition in the new-building prices of vessels, driven by factors related to the demand/supply side (Adland et al., 2017). For instance, in 2020, a 10,000–11,000 TEU vessel was about $34 million cheaper than a 13,000–14,000 TEU containership. By February 2024, the price gap had narrowed to just $1.5 million, with both vessel sizes priced around $158 million.

Figure 2.17: Containerships' new-building prices across different vessel sizes



Source: Own compilation based on Clarkson's Research NV (2025)

Generally, it is suggested that new-building prices have increased over the past five years, especially in 2024, indicating that vessel characteristics that meet the IMO and EU decarbonization targets, as well as the timing of investment, are critical considerations for investors' profitability. For example, a shipowner who decided to order a vessel at the end of 2024 would have had to bear higher capital costs compared to the decision to order a vessel in 2020. As will be extensively discussed in Essay 2.4.2, alternative fuel vessels have been introduced as options to meet IMO and EU decarbonisation targets, with China, the Republic of Korea, and Japan being the central shipbuilding regions for containerships. Nevertheless, substantial new-building costs exist for LNG and hybrid-fueled container ships, adding further complexity to investment decisions in the new building market.

In sum, the new-building industry in the liner container shipping market has been characterised by intense volatility and fluctuation, driven by different economic conditions. The two most profound periods that significantly impacted the new-building sector were the years 2003–2008, when development in China led to shifts in the market by introducing larger-capacity vessels, and the years 2020–2024, following the market disruption caused by COVID-19 and other geopolitical events. Those periods were characterised by high earnings in both the time-charter and spot markets, increasing orderbook value, and new-building prices. It was also observed that as the vessel size rises, the new-building prices also increase, but under different market conditions, investors may prefer a specific vessel size and characteristics that can bring it to competitiveness among different vessel capacities (Clarksons research, 2010, 2025). Finally, it was observed that over the period following the economic crisis in 2009, the market revealed a relatively low new-building order book, driven also by uncertainty related to upcoming IMO and EU decarbonisation regulations, which contributed to the postponement of investment decisions.

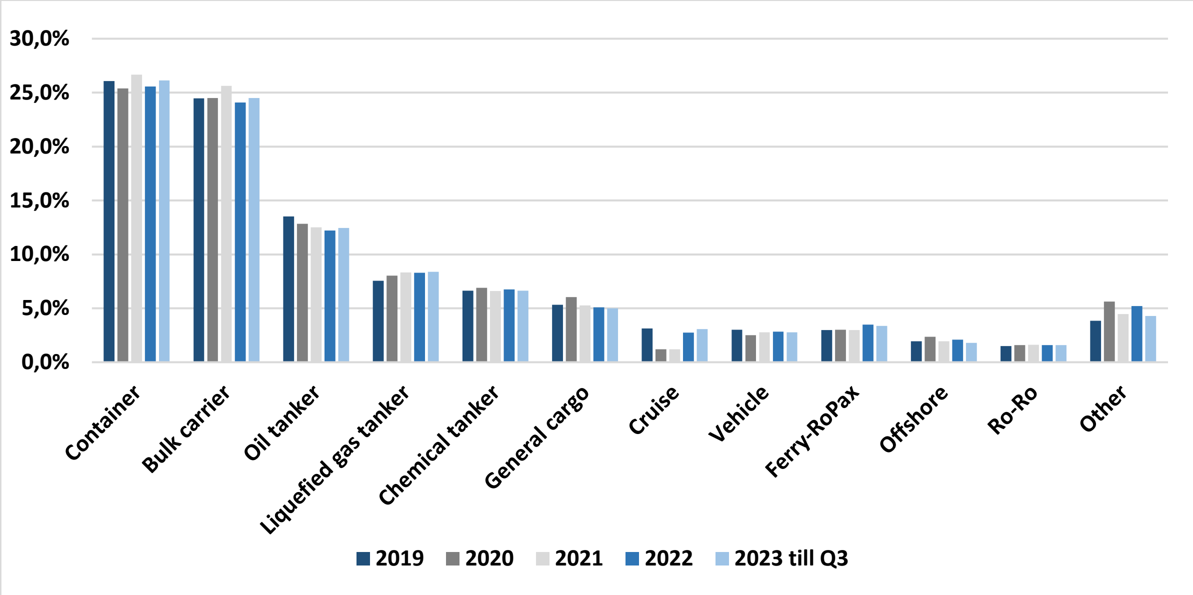
2.4 Challenges for the Shipping Industry

This subsection focuses on the challenges posed by decarbonisation to the container liner shipping industry and the regulatory responses introduced by the IMO and the EU. While previous sections emphasised the industry's strategic role in global trade and capital markets, containerships also represent a major source of maritime greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2). In response, the IMO and EU have implemented a range of regulatory instruments to improve vessel efficiency, reduce emissions, and promote the adoption of low- and zero-carbon technologies. This includes global measures such as the EEDI, EEXI, and the CII frameworks, as well as regional policies like the EU's Fit for 55 package, FuelEU Maritime, and the expansion of the EU ETS. Together, these efforts shift the regulatory landscape, imposing increasingly stringent decarbonisation requirements that reshape ship design, fuel choices, and investment behaviour across the container shipping sector.

2.4.1 IMO and EU Regulations Towards Decarbonisation

The previous subsections highlighted the strategic importance of the container liner shipping industry in facilitating global trade, its worldwide expansion, and the central role of its three primary markets (the freight market, the newbuilding market, and the second-hand market) as the core domains of investment activity for shipping stakeholders. Despite its pivotal contribution to international trade, the container liner shipping industry faces growing attention due to its environmental impact, particularly emissions resulting from vessel operations. Ships emit both greenhouse gases (GHGs) and other pollutants, including carbon dioxide (CO_2), sulphur oxides (SO_x), nitrogen oxides (NO_x), and methane (CH_4), which contribute to air pollution and climate change. According to *OECD Databas*e (2025), among all vessel types, tankers, bulk carriers, and containerships are the dominant sources of international GHG emissions, collectively accounting for approximately 82% of the shipping sector's emissions. As illustrated in Figure 2.18, CO_2 emissions across vessel categories remained relatively stable from 2019 through the third quarter of 2023. Containerships consistently exhibited the highest share of CO_2 emissions in the maritime sector, ranging from 25.4% to 26.7% between 2019 and the third quarter of 2023, placing them among the top contributors to GHG emissions in international shipping.

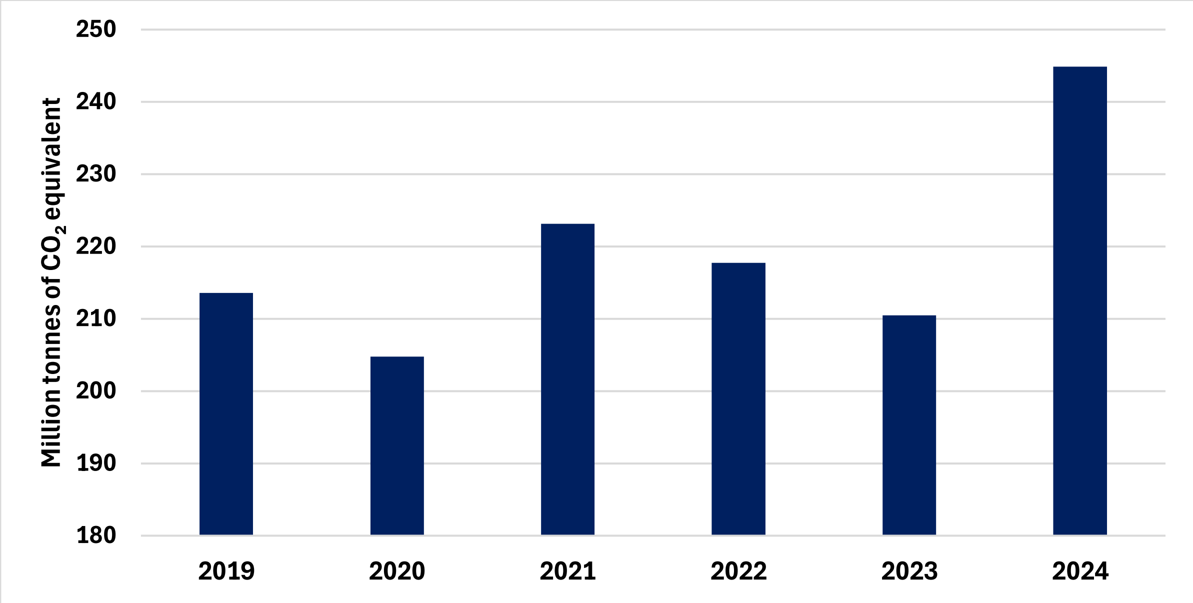
Figure 2.18: Shares of CO2 emissions from global shipping (%) by ship type, 2019-2023- Q3



Source: Own compilation based on OECD database (2024)

As illustrated Figure 2.19, container CO_2-equivalent emissions fluctuated sharply between 2019 and 2024, with the sector experiencing a notable decrease in 2020 due to the COVID-19 pandemic's disruption of global trade, followed by a strong rebound and record-breaking levels in 2024, when emissions surged to roughly 244,85 million tonnes of CO_2. This increase was driven primarily by heightened demand and longer voyages resulting from geopolitical tensions, such as the Red Sea crisis, which led ships to take longer, alternative routes.

Figure 2.19: Annual CO_2 equivalent emissions from container liner shipping, 2019–2024 (million tonnes)



Source: Own compilation based on OECD database (2024)

In response to growing concerns over maritime GHG emissions, in 2018, the IMO adopted a GHG reduction strategy 2018, establishing an initial target to reduce total annual GHG emissions from international shipping by at least 50% by 2050 compared to 2008 levels. In November 2021, the IMO aligned with the Paris Agreement and the Glasgow Climate Pact (COP26), setting an ambition of achieving 0% GHG emissions by 2050 through revisions to its strategies regarding vessel impact assessments and fuel availability reviews. Moreover, one of the key measures introduced by the IMO is the EEDI, formally adopted during the 62nd session of the *Marine Environment Protection Committee (MEPC 62)* through amendments to MARPOL Annex VI, addressing air pollution from ships. Effective on January 1, 2013, these amendments mandate progressively stricter EEDI standards for new vessels to reduce CO_2 emissions in international shipping. EEDI implementation began with Phase 0 (2013–2015), establishing baseline efficiency levels, while subsequent phases introduced increasingly stringent targets, with Phase 1 (2015–2019) required a 10% improvement, and Phase 2 (2020–2024) raised this to 20%, while Phase 3, starting from January 2025, aims for CO_2 emissions reduction up to 30%, varying according to ship type and size.

Furthermore, on November 1, 2022, the IMO adopted MEPC 76 and brought into force the Revised MARPOL Annex VI, including the CII and the EEXI as carbon intensity measures. More specifically, from January 1, 2023, by establishing annual CII and CII ratings, vessels are required to calculate their EEXI following technical means to improve their energy efficiency in the short term and thereby reduce their greenhouse gas emissions (IMO, 2022). Under these measures, vessels will be rated from A (most efficient) to E (least efficient), with increasingly stringent thresholds being approached by 2030. A ship rated D for three consecutive years or E once must update its Ship Energy Efficiency Management Plan (SEEMP) with a Corrective Action Plan (CAP) that outlines how the ship will achieve at least a C rating in future years (IMO, 2022).

In July 2023, the IMO adopted MEPC 80 (IMO, 2023), setting ambitions that include enhancing the carbon intensity and energy efficiency of new ships, reducing the carbon intensity of international shipping by at least 40% by 2030 compared to 2008 levels, and increasing the uptake of low-emission technologies to at least 5%, with a goal to reach 10% by 2030. It aims to achieve net-zero GHG emissions from international shipping by or around 2050, including a 20-30% reduction in GHG emissions by 2030 and a 70-80% reduction by 2040, compared to 2008. Table 2-1 summarises the IMO regulations aiming to decarbonise the shipping sector. Furthermore, in 2023, the IMO introduced Lifecycle Assessment (LCA) guidelines for marine fuels, offering a standardised method to evaluate GHG emissions across the entire energy chain. The methodology distinguishes between the well-to-tank stage, which includes emissions from extraction, processing, and delivery of the fuel to the vessel, and the tank-to-wake stage, which covers the emissions released during onboard combustion. By adopting this full “well-to-wake” perspective, the IMO aims to ensure that decarbonisation efforts in international shipping do not simply shift emissions to other sectors of the energy system (IMO, 2024). For shipowners, the LCA guidelines act indirectly in their investment strategies by defining which fuels are considered sustainable, thereby shaping long-term fuel choices.

Table 2-1: IMO regulations aiming to decarbonise the shipping sector

Organisation	Year of effect	GHG Emission Reduction Measures	Details
IMO	2013	- Introduction of EEDI for new ships.- SEEMP for all ships.	- Introduction of EEDI for new ships.- SEEMP for all ships.
	2018	Initial IMO strategy on reduction of GHG emissions by at least 50% by 2050.	- Exploration of market-based measures to incentivise emissions reduction.
	2023	CII measure into effect	- Development and adoption of the Carbon Intensity Indicator (CII) to measure ships' operational efficiency annually.
	2030	Carbon intensity reduction by at least 40% compared to 2008	-Focuses on improving shipping efficiency and adopting cleaner technologies.
	2040	Total GHG emissions reduction by at least 70%, striving for 80% compared to 2008	Revised targets include a more ambitious reduction than initially planned, focusing on well-to-wake emissions analysis and lifecycle GHG emissions reduction. - Adoption and scaling up of alternative fuels and clean technologies.
	2050	Net-zero emissions by 2050.	Aims for a phase-out of GHG emissions as soon as possible within this century. Encourages innovation and transition to alternative fuels and technologies.

Source: Own compilation based on IMO as of 2025

Table 2-2 summarises the EU regulations aiming to decarbonise the shipping sector. Under the European Commission's "Fit for 55" legislative package, introduced in 2021, ships must reduce emissions by 55% relative to 1990 levels by 2030 and achieve climate neutrality by 2050 (European Commission, 2021). Maritime transport also entered the EU Emissions Trading System in 2024, covering 40% of verified emissions from applicable ships, rising to 100% by 2026 (European Commission, 2023). Furthermore, EU allowance prices are expected to climb from €76.9/tCO_2 in 2025 to €92.5/tCO_2 in 2026 (Reuters, 2024), raising costs for conventional vessels, while from 2025, the FuelEU Maritime regulation will require a 2% cut in fuel GHG intensity, rising to 80% by 2050 (European Commission, 2023). Moreover, the Carbon Border Adjustment Mechanism (CBAM), starting in 2026, will impose carbon costs on imported shipbuilding materials such as steel (European Commission, 2025), increasing the cost for fossil-fuel vessels and incentivising investment in low-carbon designs.

Table 2-2: EU regulations aiming to decarbonise the shipping sector

Organisation	Year of effect	GHG Emission Reduction Measures	Details
EU	2013	EU ETS Phase III	- Launch of the EU ETS Phase III, increasing auctioning of allowances and tightening the cap.
	2018	EU ETS Phase IV	- Revision of the EU ETS for Phase IV, including measures to strengthen the system and the introduction of the Market Stability Reserve.
	2021	"Fit for 55" Package	A set of proposals to ensure the EU meets its climate target of reducing net greenhouse gas emissions by at least 55% by 2030. Includes revisions to the EU ETS, new targets for renewable energy and energy efficiency, amongst others.
	2025	FuelEU	-Increase the demand for and consistent use of renewable and low-carbon fuels- GHG intensity of fuels used by a ship to be reduced by 2%, compared to 2025 and 80% by 2050
	2026	Carbon Border Adjustment Mechanism(CBAM) reporting obligations to apply	A mechanism to establish an equitable price for carbon emissions generated during the production of carbon-intensive goods entering the EU
	2030	Net emissions reduction by at least 55% compared to 1990 levels	- EU Emissions Trading System (EU ETS) for power, aviation, and large industrial sectors.- Regulations on land use, land-use change, and forestry (LULUCF).- Renewable Energy Directive.- Energy Efficiency Directive.
	2040	Net emissions reduction by 90% compared to 1990 levels	- Strengthening and expansion of the EU ETS.- Increased investments in clean technologies and innovation.- Enhanced energy efficiency and renewable energy targets.
	2050	Climate neutrality - an economy with net-zero GHG emissions	- Comprehensive implementation of the European Green Deal.- Just Transition Mechanism to support regions most affected by the transition.

Source: Own compilation based on the EU Commission as of 2025

In addition to the IMO and EU frameworks, several national policies directly influence the shipping market. For example, in the United States, the Inflation Reduction Act (IRA, 2022) introduces tax credits and subsidies for clean hydrogen, renewable fuels, and carbon capture technologies, indirectly improving the cost competitiveness of alternative bunkers. Additionally, the Clean Fuel Production Credit, ranging from \$0.20 to \$1.00/gal applies to low-emission fuels, including renewable methanol, advanced biofuels, and synthetic e-fuels. Although not specifically designed for maritime transport, these incentives lower the relative cost of methanol, ammonia, and other clean fuels compared to conventional ones.

Similarly, Japan and the Republic of Korea have launched green shipbuilding programs since 2021, providing subsidies, financial support for alternative fuel bunkering infrastructure, and public funds to support sectors that promote green shipbuilding and conversion activities. It is also indicated that significant shipbuilding countries and shipping companies are actively adopting green shipping technologies. For instance, Japan's Green Innovation Fund, launched in 2021, allocates 2 trillion yen (≈US\$19-20 billion), with further additions in 2022 and 2023 bringing the total to around 2.76 trillion yen, part of which is allocated to shipping and alternative fuel technologies. Meanwhile, South Korea plans to invest approximately Won 222.3 billion (~US\$151 million) in 2025 alone in green shipbuilding (construction and conversion of ~81 ships), and has committed to a US\$150 billion fund over a 10-20 year period for shipbuilding cooperation and green infrastructure. (Cho et al., 2024).

Along with this, over the last decade, the decarbonisation of container liner shipping has been increasingly reliant on the adoption of alternative fuels such as liquefied natural gas (LNG), methanol, ammonia, and hydrogen, while additional measures include operational strategies such as low speed, and technological upgrades to the existing fleet, such as exhaust gas cleaning systems (scrubbers) and eco-vessel designs (Aronietis et al., 2015; J. Pruyn, 2017; Stevens et al., 2015; Sys and Tei, 2024). Based on this, Zhao et al. (2025) indicated that conventional fuels such as very low sulfur fuel oil (3.114 tCO_2/ton) and marine gas oil (3.206 tCO_2/ton) have the highest tank-to-wake emissions, while LNG reduces emissions to 2.750 tCO_2/ton (20–30% lower than HFO) but suffers from methane slip. Furthermore, methanol achieves emissions of 1.375 tCO_2/ton and benefits from easier handling, although it has lower energy density and variable lifecycle emissions, requiring larger-capacity bunker storage on ships. Ammonia and hydrogen offer zero tank-to-wake CO_2 emissions, with ammonia providing well-to-wake reductions of up to 61% but facing toxicity and NO_x concerns, while hydrogen enables zero-carbon use when renewably produced but remains constrained by low volumetric density and storage requirements. However, it is suggested that only green hydrogen and green ammonia achieve deep lifecycle GHG reductions, but without carbon pricing or incentives, their high costs and limited supply restrict their competitiveness, while ammonia also requires NOx and N_2O control systems (Zou and Yang, 2023).

Beyond fuel substitution, additional technologies can reduce the total climate impact of shipping. These include onboard carbon capture and storage (CCS) systems, wind-assisted propulsion (e.g., rotor sails and kite systems), hybridization with batteries for auxiliary power, and efficiency-enhancing measures such as air lubrication, waste-heat recovery, and optimized hull and propeller designs. Collectively, these measures address both emissions and environmental impacts, providing a more holistic decarbonisation pathway for the container shipping sector (Kondratenko et al., 2025).

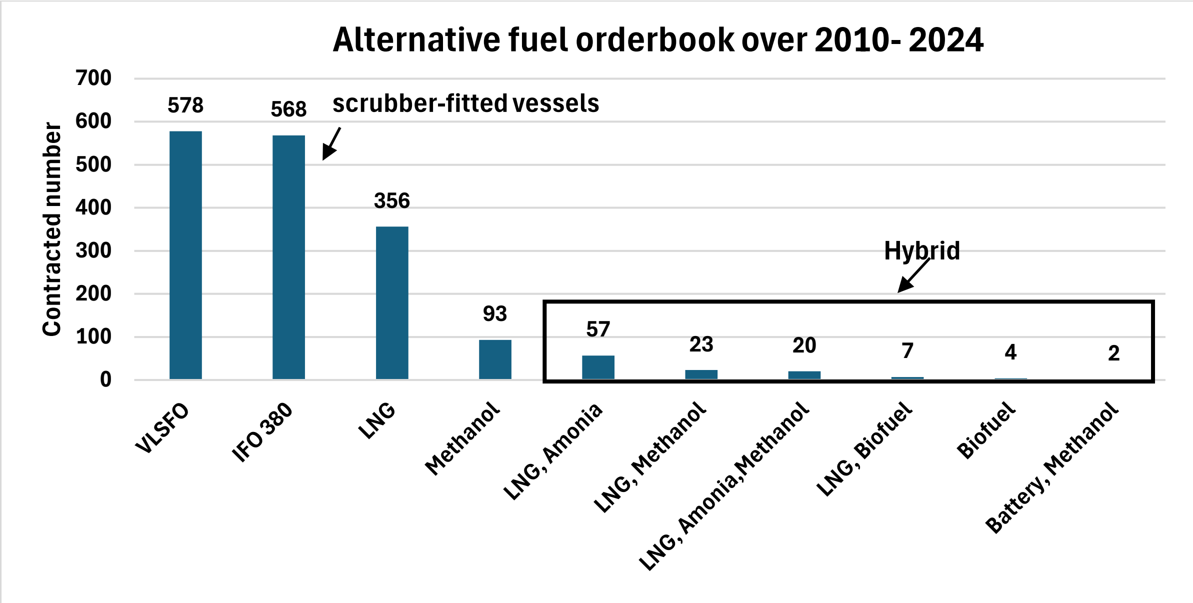
Therefore, it is evident that the transition toward low-carbon shipping involves a complex balance of fuel availability, technological and port infrastructure readiness, environmental performance, and economic feasibility, with methanol and LNG acting as immediate practical options, while ammonia and hydrogen represent strategic long-term solutions depending on infrastructure and regulatory progress.

2.4.2 An Overview of the Container Fleet Transition Towards Decarbonisation

To understand this market dynamic transition and shipowners' behaviour and efforts to meet the decarbonisation targets, in the container liner industry, the rest of this subsection provides an analysis based on a dataset of individual new building contracts for containerships. The dataset was provided by Alphaliner, a leading shipping industry intelligence platform that specialises in providing detailed data, analysis, and news on the container shipping market, covering the period from January 2010 to October 2024. It includes details such as the contract date, ship name, IMO number, build year, vessel specifications (vessel capacity in twenty-foot equivalent units (TEUs), deadweight (DWT), and gross tonnage (GT), fuel type, shipyard name and location, the delivery date, and the shipowner. The analysis is based on 1,708 newbuilding individual contracts for which newbuilding price data were available, representing approximately 58% of the total containership orderbook during the study period. In addition, following a similar approach to Jiang et al. (2013) and Adland, Norland, et al. (2017), all new-building contract prices were adjusted to 2024 levels using the U.S. Consumer Price Index (CPI) to account for inflation, ensuring comparability across contracts and isolating price variations driven by vessel characteristics, shipyard capabilities, and market conditions.

Figure 2.20 presents an overview of newbuilding contracts for containerships by fuel or propulsion type. Conventional fuel remains the primary choice for shipowners, with 578 containerships contracted under VLSFO, accounting for up to 2.55 million TEUs, and 568 vessels contracted using IFO 380 (57.4 million TEUs), all of which are scrubber-equipped. Furthermore, in the sample, 356 containerships of 4.59 million TEUs were specified to use LNG propulsion technology, representing the primary alternative fuel option for shipowners, while 93 vessels were designed to operate on methanol with a total capacity of 890,000 TEUs. Several vessels were equipped with dual-fuel engines, with 57 containerships designed to use both LNG and ammonia, accounted up to 644,000 TEUs, 23 using LNG and methanol with 296,000 TEUs, 20 vessels configured to operate on a combination of LNG, ammonia, and methanol, representing 152,000 TEUs, 7 contracts specify LNG and biofuel propulsion 134,000 TEUs, 4 were designed to use biofuel only 60,000 TEUs, and 2 vessels include a battery hybrid propulsion system combined with methanol totaling 2,656 TEUs.

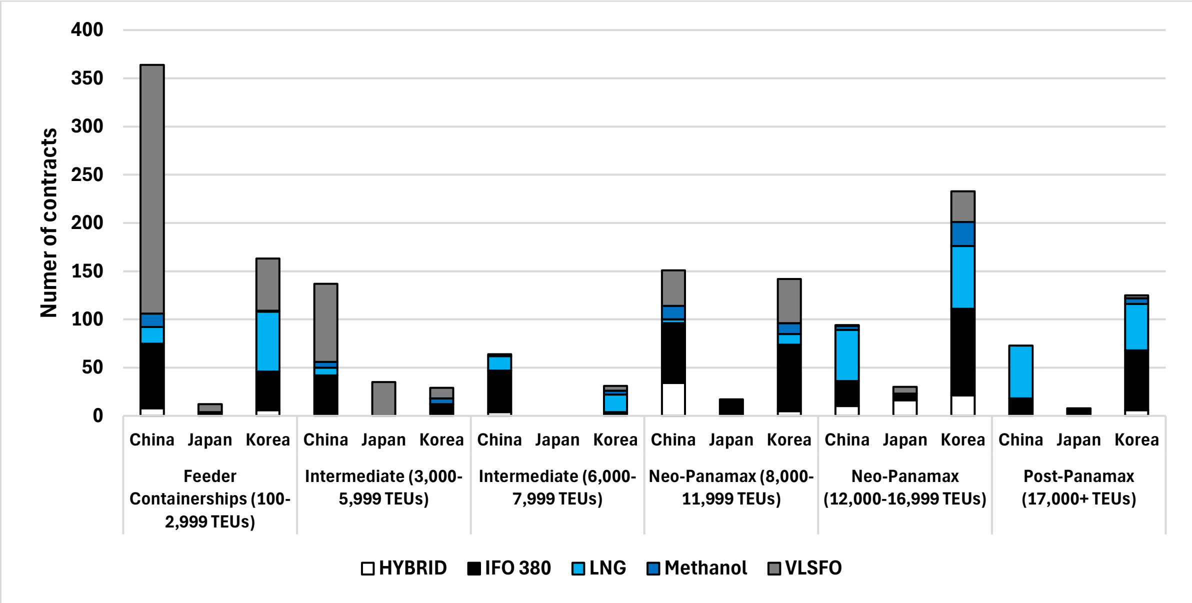
Figure 2.20: Containerships contracting order book by fuel type



Source: Own compilation based on the dataset provided by Alphaliner (2025)

Building on Figure 2.20, for greater computational tractability, container vessels equipped with hybrid propulsion systems, such as combinations of LNG-methanol, LNG-ammonia, LNG-methanol-ammonia, battery-methanol, and biofuels, are classified under the "Hybrid" category. Figure 2.21 shows the distribution of contracted containerships by vessel size, fuel type, and building regions (China, the Republic of Korea, and Japan). It is observed that China dominates in orderbook numbers across all vessel sizes, particularly in conventionally fueled ships. For instance, China accounts for 258 VLSFO-powered Feeder vessels (100–2,999 TEUs) and 90 IFO 380-powered post-Panamax vessels (17,000+ TEUs), illustrating its capability to deliver large volumes across both the small and ultra-large containership segments. The Republic of Korea is particularly active in building alternative fuels, particularly larger LNG containerships (e.g., 65 LNG-powered Neo-Panamax ships (12,000–16,999 TEUs) but also in smaller vessel sizes, including 62 LNG-powered Feeders. Japan, though with lower contract volumes overall, tends to obtain orders, particularly in Neo-Panamax LNG vessels, with 53 containerships, and retains a notable share of conventional fuel orders in the intermediate segment.

Figure 2.21: Container fleet orderbook by alternative fuel type, building region, and vessel size over January 2010 – October 2024

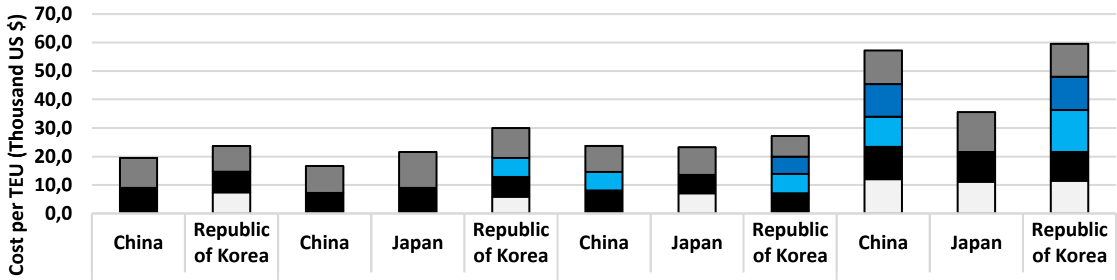


Source: Own compilation based on the dataset provided by Alphaliner (2025)

Figure 2.22 illustrates the average cost per TEU (in US dollars) for contracted containerships by fuel type across major shipbuilding countries, China, the Republic of Korea, and Japan, under different EEDI regulatory phases. During the pre-EEDI period (2010–2012), vessel orders were primarily for IFO 380 and VLSFO-fueled containerships. Average costs per TEU ranged from approximately \$7,150 to \$10,540, with China showing higher costs for VLSFO vessels. In EEDI Phase 0 (2013–2014), the Republic of Korea signed its first LNG-fueled contracts with an average cost of \$6,730 per TEU, while hybrid vessels were also contracted in the Republic of Korea (\$5,800 per TEU) and China (\$7,380 per TEU). Japan's new-building contracts primarily included conventional fuels, with VLSFO reaching the highest average cost during this phase at \$12,560 per TEU. During EEDI Phase 1 (2015–2019), the uptake of alternative fuels modestly increased. In all three countries, there were LNG-fueled containership contracts, with average costs ranging from \$6,430 to \$6,850 per TEU.

Methanol-fueled vessels were contracted only in China ($6,050 per TEU), while hybrid systems remained limited. In EEDI Phase 2 (2020–2024), the adoption of alternative fuels accelerated significantly. LNG reached the highest recorded cost in the Republic of Korea at $14,620 per TEU, while methanol rose to $11,650 and $11,480 in China. Hybrid propulsion systems showed the highest overall cost levels, $12,060 in China, $11,150 in Japan, and $11,390 in Korea, highlighting the increasing capital investment associated with stricter energy efficiency, technological, and decarbonisation requirements.

Figure 2.22: Container fleet orderbook by alternative fuel type and building region (2010–2024), aligned with EEDI phases.

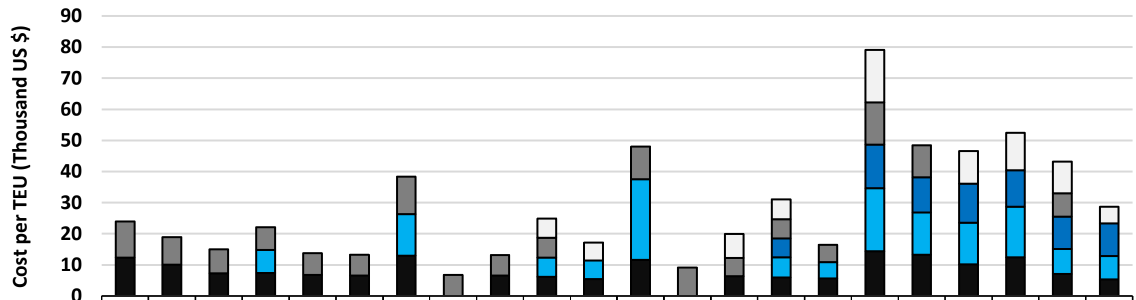


	pre_EEDI period (January 2010 - December 2012)		EEDI_phase_0 (January 2013 - December 2014)			EEDI_phase_1 (January 2015 - December 2019)			EEDI_phase_2 (January 2020 - October 2024)		
	China	Republic of Korea	China	Japan	Republic of Korea	China	Japan	Republic of Korea	China	Japan	Republic of Korea
VLSFO	10,5	9,0	9,4	12,6	10,5	9,3	9,6	7,2	11,7	14,0	11,6
Methanol								6,0	11,5		11,6
LNG					6,7	6,4		6,9	10,6		14,6
IFO 380	9,0	7,3	7,1	9,0	7,0	8,1	6,5	7,1	11,3	10,4	10,3
HYBRID		7,4			5,8		7,1		12,1	11,1	11,4

Source: Own compilation based on the dataset provided by Alphaliner (2025)

Similarly, Figure 2.23 provides a detailed analysis of the interaction between fuel adoption, vessel size, and the EEDI regulatory phases. In the pre-EEDI period (2010–2012), conventional fuels like IFO 380 exhibited clear economies of scale, with costs per TEU decreasing from $12,300 for small vessels to $6,600 for ultra-large containerships. Similar trends were observed for VLSFO's vessels. During EEDI Phase 0 (2013–2014), LNG-fueled ships were valued at around $13,300 per TEU in medium-sized and big vessels, alongside hybrid propulsion systems priced between $6,200 and $6,300 per TEU. Conventional fuels maintain scale advantages, with costs declining as vessel size increases. EEDI Phase 1 (2015–2019) saw modest growth in alternative fuels, with LNG stabilising at $6,000–$6,500 per TEU and methanol introduced at $6,000 per TEU. Hybrid systems rose to $7,700 per TEU in mid-sized ships, while IFO 380 remained cost-effective for bigger vessels. In EEDI Phase 2 (2020–2024), the adoption of alternative fuels accelerated. LNG costs peaked at $20,300 per TEU for small vessels but dropped to $7,500 for the largest containerships, highlighting economies of scale. Methanol and hybrid propulsion costs were highest in smaller ships but decreased significantly with size. These trends indicate that regulatory pressures drive fuel diversification, yet smaller vessels face higher per-unit costs, limiting their ability to absorb green technology investments efficiently.

Figure 2.23: Container fleet orderbook by alternative fuel type and vessel size (2010–2024), aligned with EEDI phases



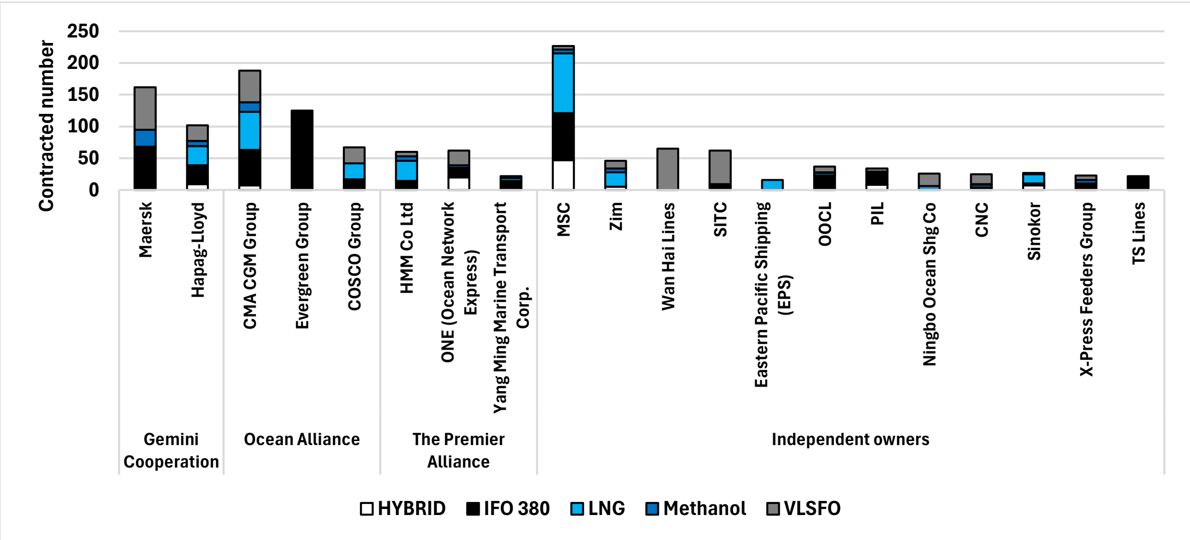
	pre_EEDI period (January 2010 - December 2012)						EEDI_phase_0 (January 2013 - December 2014)					EEDI_phase_1 (January 2015 - December 2019)					EEDI_phase_2 (January 2020 - October 2024)					
	100-2,999 TEUs	3,000-5,999 TEUs	6,000-7,999 TEUs	8,000-11,999 TEUs	12,000-16,999 TEUs	17,000+ TEUs	100-2,999 TEUs	3,000-5,999 TEUs	8,000-11,999 TEUs	12,000-16,999 TEUs	17,000+ TEUs	100-2,999 TEUs	3,000-5,999 TEUs	8,000-11,999 TEUs	12,000-16,999 TEUs	17,000+ TEUs	100-2,999 TEUs	3,000-5,999 TEUs	6,000-7,999 TEUs	8,000-11,999 TEUs	12,000-16,999 TEUs	17,000+ TEUs
HYBRID										6,2	5,7			7,7	6,4		16,9		10,5	12,0	10,2	5,3
VLSFO	11,6	8,9	7,7	7,3	6,9	6,6	12,1	6,8	6,6	6,3		10,4	9,1	5,9	6,2	5,6	13,6	10,3			7,5	
Methanol															6,0		14,0	11,3	12,5	11,7	10,3	10,5
LNG				7,4			13,3			6,2	6,0	26,0			6,5	5,2	20,3	13,6	13,4	16,3	8,1	7,5
IFO 380	12,3	10,0	7,3	7,4	6,8	6,6	12,9		6,6	6,1	5,4	11,6		6,3	6,0	5,7	14,4	13,2	10,2	12,4	7,0	5,4

Source: Own compilation based on the dataset provided by Alphaliner (2025)

Lastly, Figure 2.24 represents the distribution of contracted newbuilding containerships by fuel type across major liner shipping alliances and independent owners. Within the

Gemini Cooperation, Maersk shows strong investment in methanol vessels alongside VLSFO and IFO 380, while Hapag-Lloyd adopts a balanced mix including LNG, hybrid, methanol, and conventional fuel containerships. In the Ocean Alliance, CMA CGM has the most diversified portfolio, with significant shares of LNG, methanol, hybrid, and conventional fuels. In contrast, Evergreen remains almost entirely reliant on IFO 380 vessels, while COSCO adopts a moderate LNG share and a mix of IFO 380 and VLSFO containerships. Within the Premier Alliance, HMM leads in LNG, with additional contracts in methanol, VLSFO, and IFO 380. ONE and Yang Ming show more varied adoption, notably hybrid and VLSFO, with limited LNG use. Among independent owners, MSC holds the largest orderbook, led by LNG, IFO 380, and hybrid systems. ZIM also shows notable LNG and methanol adoption. Lastly, Wan Hai and SITC focus exclusively on VLSFO, while EPS concentrates on LNG, while other owners, such as OOCL, PIL, and Sinokor, adopt mixed approaches involving both conventional and alternative fuels.

Figure 2.24: Fuel Profile of Top-20 Container-Shipowners Orders



Source: Own compilation based on the dataset provided by Alphaliner (2025)

Overall, the data illustrate a clear divergence in decarbonisation strategies across operators. European carriers, such as Maersk, CMA CGM, and MSC, are actively contracting vessels with alternative propulsion systems, particularly LNG and methanol, reflecting their increased regulatory exposure under the EU ETS and FuelEU. In contrast, many Asian shipowners, including Evergreen and OOCL, remain concentrated in conventional fuel technologies, with LNG serving as the main transition pathway, reflecting differing regulatory exposures, strategic preferences, and technological adoption pathways that shape investment choices within the container shipping industry.

2.5 Discussion and Regulatory Scenarios for the Container Shipping Markets Under Decarbonisation Pressures

This part of the analysis provides a discussion based on the observed market trends and developments, and building on these trends, the following section develops three regulatory scenarios, "AS IS," "Positive," and "Negative" scenarios, to illustrate how different policy pathways may influence market behaviour across the time-charter, the second-hand, and the new building market.

2.5.1 Discussion

From the analysis discussed above, it is clear that the global container liner shipping industry has experienced noticeable growth and transformation over the past three decades. As of February 2025, container throughput reached approximately 868 million TEUs, with China emerging as the leading contributor to global container trade, with its container throughput increasing from approximately 250 million TEUs in 2024, representing 33.76% of the global containerised trade (Figure 2.1). Over the same period, the containership fleet expanded not only in numbers but also in scale, with larger vessel classes such as the neo-Panamax and post-Panamax segments dominating global capacity (*Figure 2.2*). Furthermore, it was observed that the containership fleet has evolved in both size scale and structure, representing the transition towards larger and more efficient vessels achieved through economies of scale.

Additionally, the market concentration has intensified, with the top 10 carriers controlling 85.6% of global capacity in 2025, illustrating the increasing concentration and strategic realignment among major market players in the container liner shipping industry (*Figure 2.6*) in decarbonisation strategies across shipping companies. While some shipowners, like Maersk, CMA CGM, and MSC, are actively contracting vessels with alternative propulsion systems, particularly LNG and methanol, others (e.g. Evergreen, OOCL, etc.) remain concentrated in conventional fuel technologies, reflecting differing risk, regulatory exposures, and technological adoption pathways within the container shipping industry (Figure 2.24). This trend also highlights the investment strategies of larger companies, which often take the lead in adopting greener technologies, setting a benchmark that smaller firms tend to follow.

The review of the three principal maritime markets, namely the freight market, second-hand (S&P) market, and the newbuilding market, reveals distinct patterns under regulatory and geopolitical pressure. Starting from the freight market, it was highlighted that both freight and time-charter rates are impacted by market conditions and market expectations, with bigger vessels being associated with higher earnings. A significant surge in the freight market was observed during post-COVID-19, due to supply disruptions and limited vessel availability, resulting in a cash surplus, fueling green investments and vessel orders (Clarksons research, 2025).

Continuing with the sales and purchase market, it was indicated that this market is dominated by smaller vessels (e.g., feeder and intermediate containership sizes), which allows shipowners to respond quickly to market conditions without the lead times required for newbuilds. Moreover, peaks in sales activity of second-hand vessels, such as in 2004, 2017, and 2021, correspond to unexpected economic booms, when shipowners focus on the immediately available capacity. Furthermore, the newbuilding market is deeply cyclical and highly influenced by market expectations for freight demand, fuel costs, and regulatory changes. It was observed that the orderbook experienced two notable peaks. The first, between 2005 and 2008, was largely fuelled by China's rapid trade growth, and the second, between 2020 and 2024, when a combination of the low orderbook and the market recovery from COVID-19 supply disruptions resulted in unprecedented cash inflows for shipowners, commonly referred to as the "cash bubble".

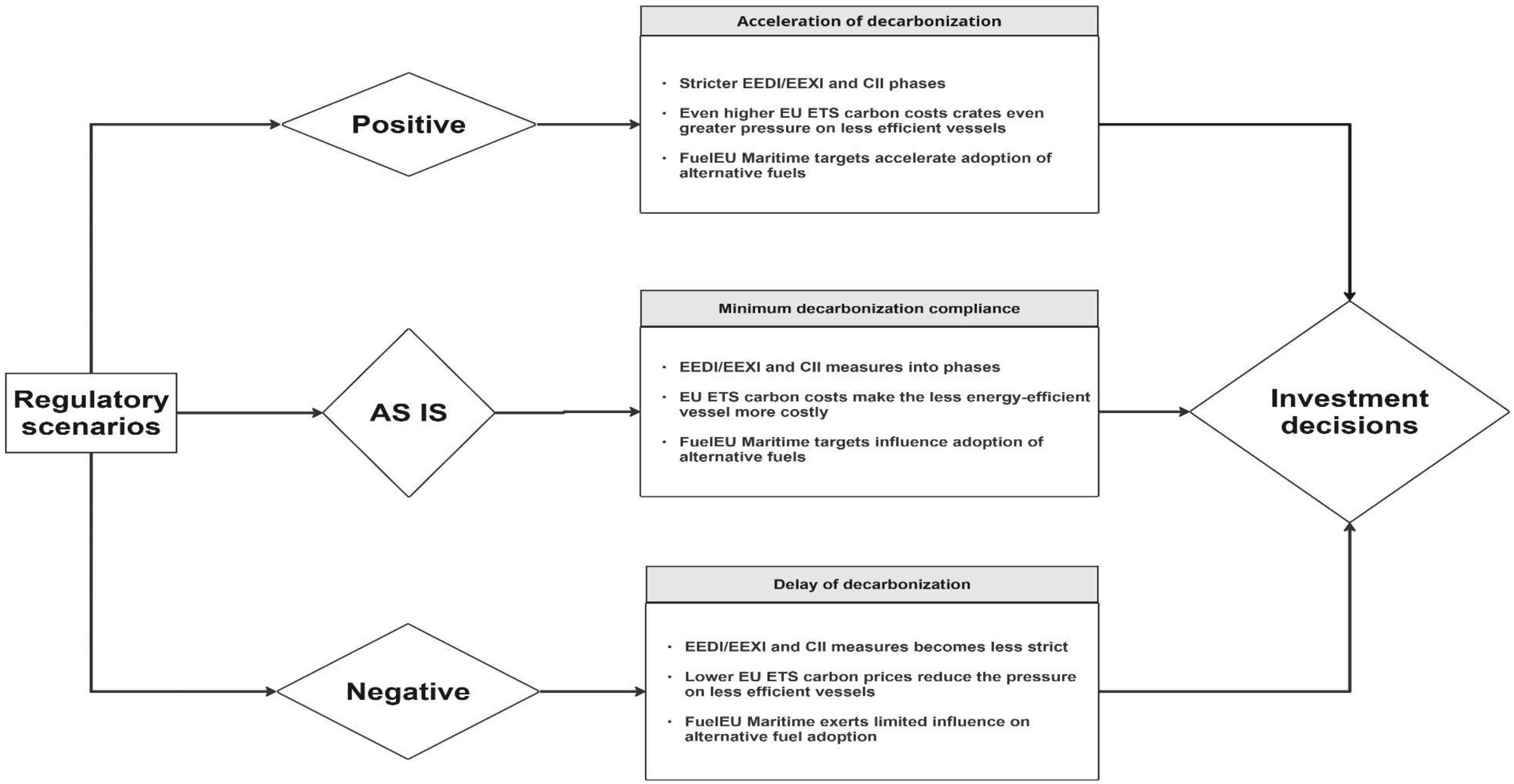
At the same time, the age structure of the fleet indicates that a significant share of capacity is over 15 years old and will require replacement in the coming decade, particularly for vessels that do not comply with IMO and EU regulations. To this extent, a central concern is the industry's environmental footprint, particularly its contribution to global GHG emissions, as containerships are the largest contributors to maritime CO_2 emissions, accounting for approximately 25% - 27% of global CO_2 emissions output, which surged to roughly 244,85 million tonnes of CO_2-equivalent emissions in 2024, due to geopolitical tensions, rerouting, etc. (Figure 2.19).

Overall, recent container vessel orders show a strong shift toward green technologies, with LNG, methanol, and hybrid systems emerging as promising alternatives that will help the industry to achieve the IMO and EU decarbonisation targets. To this extent, regulatory measures, including the EEDI, CII, EU ETS, etc., provide significant influence on the investment strategies across the three shipping markets.

2.5.2 Regulatory Scenarios

Building on the current market trends, Figure 2.25 illustrates three alternative scenarios (*'As Is', Positive,* and the *Negative scenario)* to illustrate how IMO and EU decarbonisation regulations may influence market interactions and investment decisions across the time-charter, second-hand, and newbuilding markets. These scenarios isolate the regulatory dimension as the primary driver that affects the investment strategies, assuming that trade growth and technological progress remain constant. By focusing on emission-related measures, the analysis focuses on how regulatory changes can influence market dynamics and the strategic choices of shipowners.

Figure 2.25: Regulatory scenario for the investment decisions



Source: Own compilation based on IMO and EU regulations toward decarbonisation

2.5.2.1 "AS IS" Regulatory Scenario

The first ("AS IS") scenario assumes the gradual implementation of the EEXI, EEDI, and CII, while based on the EU ETS, vessels entering the European ports will need to cover 100% of their CO_2 emissions from 2026, while EU CO_2 allowance prices are expected to set €92.5/tCO_2 in 2026 (Reuters, 2024), raising the cost of conventional-fueled ships. At the same time, the FuelEU Maritime regulation requires a progressive reduction in fuel GHG intensity, starting at 2% in 2025 and reaching 80% by 2050 (European Commission, 2023), while the CBAM raises the relative competitiveness of low-carbon vessels by increasing costs for conventional vessels.

Under this scenario, more energy-efficient vessels are expected to command time-charter rate premiums, although the extent to which these premiums are systematically reflected in their contracts remains uncertain. In addition, in the second-hand market, small feeder and intermediate vessels remain the most actively traded sizes, with older ships experiencing steady pressure to meet decarbonisation requirements. To this extent, evaluating whether active trading strategies can provide substantial revenues compared to the buy-and-hold approach can provide insights for shipowners' investment strategies, considering also the potential for vessel retrofitting. In the newbuilding market, the newbuilding orderbook is expected to consist of both conventional and alternative-fuel vessels, with the price premiums associated with alternative-fuel designs being a key parameter for informed investment decisions.

2.5.2.2 "Positive" Regulatory Scenario

The "positive" scenario considers the environmental sustainability and the emission neutrality, assuming strong regulatory alignment between IMO and the EU, with stricter enforcement measures (i.e., stricter energy efficiency ratings, etc.), while the EU carbon allowance prices are assumed to rise even higher, putting a lot of pressure on less efficient vessels.

In the time-charter market, more energy-efficient vessels are expected to secure significant premiums, as charterers will primarily focus on acquiring more energy-efficient capacity, influenced by higher carbon prices and stricter regulations. Assessing the current price premiums associated with energy efficiency in time-charter rates, therefore, provides valuable insights into shipowners' and operators' expectations regarding future investment decisions in the time-charter segment. Similarly, in the second-hand market, more energy-efficient vessels are expected to achieve higher values, as they will increasingly differentiate between compliant and non-compliant tonnage. Consequently, investment strategies must align closely with decarbonisation requirements, through active trading decisions or keeping vessels with the potential for retrofitting to meet regulatory requirements. Furthermore, alternative-fueled vessels are expected to dominate future orderbook, reflecting the industry's faster transition towards decarbonisation.

2.5.2.3 "Negative" Regulatory Scenario

The "negative" scenario assumes that world trade and technological progress remain stable, but the implementation of IMO and EU measures is only partially effective and remains weak. The EEDI, EEXI, and CII requirements will obligate vessels rated D or E to submit corrective action plans; however, in practice, this will allow older ships to continue trading in the market. The EU ETS will be implemented gradually, covering only a portion of emissions until 2026, while FuelEU Maritime obligations and CBAM measures will have less effectiveness.

In this context, charterers will potentially show lower willingness to pay premiums for fuel-efficient vessels, reducing the competitive advantage of ships that meet stricter environmental standards. Instead, charter rates would be largely determined by short-term demand dynamics, with fuel costs serving as the principal driver of time-charter rate formation. As a result, shipowners will potentially continue to rely on conventional tonnage or postpone their orders rather than committing to costly newbuilding orders with green technologies. Under such conditions, the second-hand market will become increasingly important, as it provides immediate access to fleet capacity and serves as a key mechanism for short-term investment and divestment strategies. As long as decarbonisation measures remain weakly enforced, shipowners are more likely to pursue opportunistic trading strategies in the second-hand segment by postponing long-term commitments to fleet renewal. In the newbuilding market, the high cost of alternative-fuel vessels is anticipated to discourage widespread adoption, with only a few large carriers proceeding with strategic orders, while most owners will postpone investment until stronger enforcement or clearer regulatory and technological signals emerge.

Overall, regardless of which scenario will occur, there are three research questions that frame the empirical part of this dissertation and directly impact shipowners' investment strategies across the time-charter, second-hand, and new-building markets. More specifically, Essay 2 examines the price premium for more energy-efficient vessels on the time-charter rates, which is crucial since less energy-efficient ships expose shipowners to rising emission costs. Essay 3 analyses the investments or divestment strategies in the second-hand market and compares the profitability between active trading and buy-and-hold decisions for second-hand containerships. This study provides information for shipowners who may postpone new orders to reduce their capital exposure or seek available fleet capacity. Finally, in the newbuilding market, Essay 4 assesses the cost premiums of alternative-fuel vessels compared to conventional vessels, aiming to provide insights into the cost implications linked to greener containerships. These empirical outcomes will therefore aim to provide insight into how shipowners can adapt their investment behaviour across the three main markets, considering the IMO and EU decarbonisation targets.

2.6 Conclusions

This essay conducted an exploratory analysis of the container liner shipping market. After investigating the market characteristics, evolution, and challenges towards decarbonisation, the study provided three future scenarios, aiming to highlight key concerns for the investment decision-making processes for shipowners and investors. Key findings indicated that the container liner shipping industry has experienced noticeable growth, with China emerging as the leading contributor to global container trade. It was observed that the container shipping fleet has evolved in both size and structure, with the top 10 carriers controlling 85.6% of global capacity in 2025. A clear divergence exists in decarbonisation strategies across operators, reflecting differing risk, regulatory exposures, and technological adoption pathways within the container shipping industry.

The review of the three principal maritime markets, namely the freight market, second-hand (S&P) market, and the newbuilding market, revealed distinct patterns under regulatory and economic pressures. The study highlighted that both freight and time-charter rates are impacted by market conditions and market expectations, with bigger vessels being associated with higher earnings. A significant surge in the freight market was observed during post-COVID due to supply disruptions and limited vessel availability, resulting in a cash surplus, fueling green investments and new orders. Continuing with the sales and purchase market, it was indicated that this market is dominated by smaller vessels (e.g., feeder and intermediate containership sizes), offering cost-effective, short-term solutions for shipowners. Furthermore, concerning the newbuilding market, a noticeable peak in the orderbook was observed during 2005–2008, driven by trade growth from China, and again during 2020–2024, following the supply disruptions caused by COVID-19 and earlier delays in the orderbook activity due to uncertainty related to decarbonisation measures. Recent container vessel orders have shown a strong shift toward green technologies, with LNG, methanol, and hybrid systems emerging as promising alternatives that can help the industry achieve the decarbonisation targets set by the IMO and the EU.

Finally, this essay also presented three regulatory scenarios related to future investment strategies. The "AS IS" scenario assumes a phased implementation of IMO and EU measures, the "positive" scenario presumed stricter regulations, leading to higher investments in green vessels and higher rewards for energy efficiency, while the "negative" scenario considers, less strict regulatory measures, resulting in a lower alternative-fueled orderbook, delayed investments, and increased uncertainty across the three shipping markets, potentially guiding to a prolonged decarbonisation timeline. Under these scenarios, Essays 2 to 4 examine whether more energy-efficient vessels achieve higher time-charter rates, analyse trading and timing strategies in the second-hand market, and estimate the cost premiums for alternative-fuel vessels in the newbuilding market. These empirical studies will aim to provide insight into how market dynamics, fuel efficiency, and alternative fuels affect asset values and investment decisions in the container liner shipping industry. Finally, Chapter 6 integrates the empirical results into the regulatory scenarios developed in this section and provides practical recommendations for shipowners, policymakers, and future research.

Chapter 3: Essay 2 - Evaluating the Impact of Energy Efficiency on Time Charter Rates of Containerships[6]

This essay investigates whether more fuel-efficient vessels command a premium in their time-charter contracts. Fixture contracts for container vessels from January 2020 to October 2023 are analysed to identify factors influencing charter rates, including market conditions, vessel capacity, fuel prices, and the adoption of energy-efficient technologies. Findings reveal that a 1% decrease in the attained Energy Efficiency Design Index ($EEDI_{att}$) results in a 0.10% to 0.12% increase in time-charter rates. This effect is more pronounced for eco-engine vessels, with a 1% improvement in energy efficiency resulting in a 0.18% to 0.22% increase in rates. Additionally, it is indicated that vessels equipped with eco-engines secure higher charter rates and longer contracts, demonstrating the economic benefits of adopting energy-efficient technologies.

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3.1 Introduction

As highlighted in the section 2.4.1, to deal with the rising emissions from shipping operations, in 2018, the IMO established its initial emissions reduction goals, targeting a 50% decrease by 2050 compared to the levels recorded in 2008. In July 2023, the IMO adopted its revised GHG reduction strategy, setting new ambitions that include enhancing the carbon intensity and energy efficiency of new ships, reducing the carbon intensity of international shipping by at least 40% by 2030 compared to 2008 levels, and increasing the uptake of low-emission technologies to at least 5%, aiming to reach 10% by 2030 and achieve emission neutrality by 2050 (IMO, 2023). One of the key measures introduced by the IMO is EEDI, which was formally adopted during the 62nd session of the IMO's Marine Environment Protection Committee (MEPC 62) as part of amendments to MARPOL Annex VI, which addresses the prevention of air pollution from ships (*IMO, 2011*). These amendments came into force on January 1, 2013, mandating EEDI requirements for new ships as part of the IMO's efforts to reduce greenhouse gas emissions from international shipping. The EEDI is implemented in three progressive phases: Phase 0 (2013-2015) sets the baseline for new ships; Phase 1 (2015-2019) required a 10% improvement in energy efficiency; and Phase 2 (2020-2024) increased this target to 20%. From 2025 onwards, Phase 3 will require further reductions of up to 30%, depending on the ship type and size.

Accordingly, for existing vessels, the EEXI ensures that ships already in service meet minimum energy efficiency standards. Introduced in 2023, the EEXI applies to ships built before the implementation of the EEDI and plays a crucial role in retroactively improving the energy efficiency of the global fleet. As such, the EEXI is a key regulatory mechanism that promotes a more energy-efficient global fleet, helping to restrain GHG emissions across both new and existing ships (IMO, 2021).

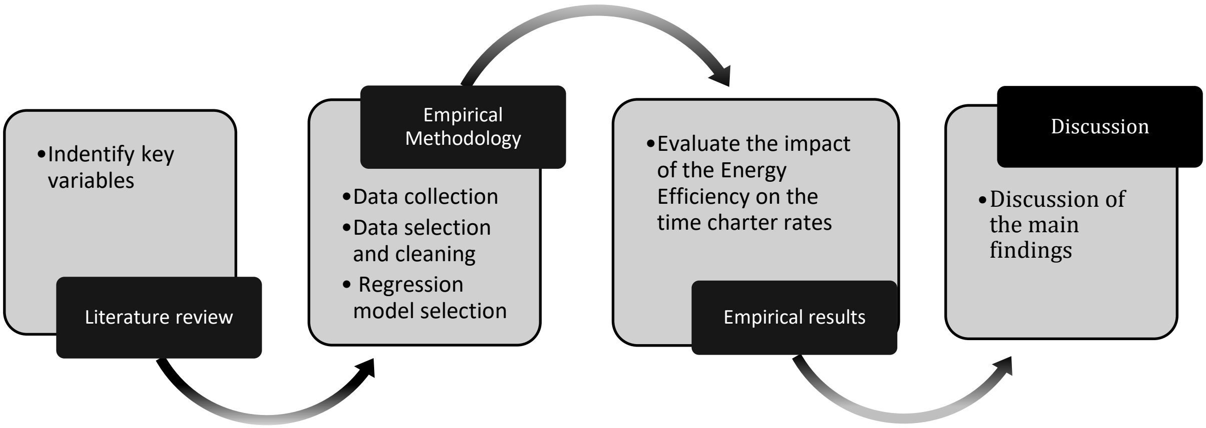
Several studies, including Aronietis et al. (2015), Stevens et al. (2015), Lee and Nam (2017), and Ross and Schinas (2019), have investigated the implementation and impact of green shipping practices and eco-friendly technologies, aiming to identify key challenges and propose effective measures to enhance their adoption and promote sustainable shipping. Next to this, various studies have investigated the barriers to the adoption of green technologies (Jafarzadeh and Utne, 2014; Rehmatulla and Smith, 2015), suggesting that principal-agent problems, particularly split incentives, and informational problems, significantly affect the implementation of energy efficiency measures. For instance, a shipowner who upgrades their fleet with fuel-saving technologies might not see an increase in charter rates, as charterers may hesitate to pay extra for these efficiencies. This discrepancy leaves shipowners weighing significant initial investments against uncertain financial gains, hindering the industry's shift towards more energy-efficient practices.

To this extent, Dirzka and Acciaro (2021) explored the principal-agent issues within the container shipping industry's charter market, analysing how split incentives and information gaps affect carbon emissions. These authors revealed that chartered vessels emit more carbon than those directly operated by their owners, suggesting that current charter practices discourage investments in energy-efficient technologies. The study also showed that adopting green technologies does not result in adequate premiums in the charter market, leading to the persistence of relatively inefficient vessels. Similar results were also indicated in the dry bulk sector, suggesting that the market does not consistently reward these energy-efficient ships with higher premiums or charter rates, often because of information gaps and the complexities of market behaviour (Agnolucci et al., 2014; Adland et al., 2017).

The present essay contributes to the existing literature by investigating whether shipowners place premiums on more fuel-efficient vessels in time charter contracts within the container shipping industry. Covering the period from January 2020 to October 2023, this study coincides with the IMO's ambitious new decarbonisation targets. The research addresses the following question: Do more fuel-efficient container ships command premiums in their time charter contracts?

To do this, a four-step approach is followed, as depicted in Figure 3.1. In step 1, the paper investigates the previous literature to identify variables impacting time charter rates and variables reflecting the energy efficiency measures. Step 2 includes data collection, selection, and cleaning, and describes the selected regression model. Step 3 provides the empirical result from the model, while the findings are discussed in the final step (step 4).

Figure 3.1: Research approach



The paper is structured as follows: Section 3.2 provides a literature review addressing challenges in the container liner shipping industry, particularly focusing on the time charter market. Section 3.3 outlines the empirical methodology, and Section 3.4 describes the data. Section 3.5 presents the empirical analysis, while Section 3.6 discusses the findings. Finally, Section 3.7 concludes the study.

3.2 Literature Review

In the time-charter market, the charterer hires a ship from a shipowner (the owner of the vessel) at a fixed rate, with the shipowner getting paid on a $/day basis for the duration of the hire period. Under the time-charter agreement, the charterer manages the transport themselves, with the voyage costs and the cargo expenses, such as fuel costs, port charges, etc., to be on the charterer's account (Pagonis and Pentheroudakis, 2019).

Regarding the container shipping industry, charterers prioritise high-quality transport services, safety compliance, and cost-effectiveness, and they often charter vessels for more flexibility and space availability (Plomaritou and Menelaou, 2020). Additionally, for shipowners, the stable cash flows provided by time-charter contracts are vital for maintenance and regulatory capital expenditures, especially in the context of increasing emission constraints and investments in fuel efficiency technologies. Such improvements can lead to extended contract durations and potentially higher time-charter charter rates, while they can also provide valuable information for alternative investment strategies as signals for the market conditions and the shipowners' future expectations (Georgoudakis et al., 2023). (Stopford, 2009). In the container liner shipping industry, short-term charters typically range from a few months to 1 year, medium-term charters last around 1 - 3 years, and long-term charters often range beyond three years (Stopford, 2009). Gencer and Tuzcuoğlu (2023) found that for containerships, the middle-term charter period was common in the pre-COVID era, beginning in 2018, but decreased in favour of more short-term and long-term charters in the post-COVID period up to October 2021. Before COVID, intermediate containerships (3,000–7,499 TEU) were usually fixed on longer contracts, while feeders (below 2,000 TEU) were mainly employed on middle-term charters at lower rates. After COVID, this pattern weakened, as feeders dominated most of the market and intermediate ships appeared in both short-term and long-term contracts at higher rates.

Given the IMO's intensified measures to reduce GHG emissions, extensive discussions have emerged regarding the adoption of greener technologies to enhance the industry's commitment to sustainable practices. To this extent, Lee and Nam (2017) investigated the implementation and impact of green shipping practices and eco-friendly vessels in major countries, indicating that despite the economic downturn and supply-demand imbalance in the shipping market, there was a noticeable shift towards the adoption of environmentally friendly technologies and practices. In a related study, Ross and Schinas (2019) analysed the energy efficiency of the global shipping fleet, aiming to identify clusters of ships with similar energy efficiency levels, measured by the EEDI, showing significant variations in energy efficiency across different segments of the shipping industry, with vessel size and age being critical factors influencing energy performance.

Nevertheless, the barriers to the adoption of green technologies in the shipping industry have also been under debate, suggesting that the efficiency gap is a result of the split incentives and informational problems between the owner and the charterer, known as the principal-agent problem (Agnolucci et al., 2014; Rehmatulla and Smith, 2015; Adland, Alger, et al., 2017; Dirzka and Acciaro, 2021). Those studies argue that shipowners act as agents, possessing greater knowledge about the ship's energy efficiency and performance, and therefore, they can have better negotiation power over charterers. Accordingly, it was suggested that if energy efficiency were accurately reflected in charter rates, there would be no principal-agent problem, and as a result, more efficient vessels would receive higher charter rates.

To this extent, Agnolucci et al. (2014) indicated that shipowners in the dry bulk market capture only a fraction of the financial benefits from energy-efficient ship designs, with owners typically retaining just 40% of the savings from improved energy efficiency. A follow-up analysis from Adland et al. (2017) suggested that under normal market conditions, only 14–27% of fuel savings were reflected through higher rates, while during market "booms," the relationship reversed, and energy-efficient vessels did not consistently command a premium. Analogous study in the container shipping industry from Dirzka and Acciaro (2021) revealed that chartered vessels emit more carbon than those directly operated by their owners, suggesting that current charter practices discourage investments in energy-efficient technologies, emphasising the need for policies that address these inefficiencies. The study also showed that adopting green technologies does not result in adequate premiums.

Rehmatulla and Smith (2020) investigated the adoption of energy efficiency technologies in the maritime transport sector, finding that firms with a significant portion of their ships on time charter implement these technologies to a greater extent. This outcome challenges the 'efficiency' problem, suggesting that shipowners may still invest in such technologies when the charterer covers the fuel costs but does not bear responsibility for energy efficiency investments. The study also identified potential factors contributing to this higher implementation, including the influence of sector-specific dynamics and the bargaining power of charterers, especially in the wet-bulk sector, suggesting that the shipping market might partially self-correct in addressing the split incentive efficiency problem.

Overall, the empirical literature has examined the drives for fuel efficiency in a broader aspect of the industry, while the microeconomic determinants of freight rates, including vessel quality and energy efficiency, and their impact on the time-charter rates, were only explored in the dry bulk industry, revealing complexities in time charter and voyage charter markets. These studies suggest that while energy-efficient vessels might not always receive a premium in charter rates due to market and informational barriers, they can lead to better contracts and utilisation rates.

However, it is still being determined whether the push towards making containerships more fuel-efficient and environmentally friendly financially benefits shipowners. Considering the literature above and given the IMO's intensified measures to reduce GHG emissions, this Essay investigates whether shipowners in the container industry place premiums on more energy-efficient vessels in their time-charter contracts, addressing a gap in the current literature covering the post-COVID-19 period.

3.3 Methodology

This section outlines the selection of variables for the regression model, including their expected influence on time charter rates. The key variables encompass macroeconomic indicators, vessel characteristics, and factors relevant to fuel efficiency and market conditions. The selection of these variables is based on their significant impact on time charter rates, as established in previous research and industry practices (Cariou and Wolff, 2013; Agnolucci et al., 2014; Adland, Alger, et al., 2017; Shin et al., 2019; Tuzcuoğlu and

Gencer, 2023). The section also provides the regression model used in the empirical part of this essay.

3.3.1 Variable Selection

To analyse the impact of vessel energy efficiency on time charter rates for containers, a dataset with individual fixtures was obtained from Clarksons Ship Intelligence Network (SIN) from January 2020 to October 2023. It includes details such as the charter date, ship name, build year, vessel capacity in TEUs (twenty-foot equivalent units), charterer description, laycan (the agreed time range for the ship to be ready to load), length of the charter period, the daily charter rate in USD, and the shipowner. The initial sample comprised 4,815 observations. After excluding contracts that lacked information on time-charter rates (501 observations) and observations for vessels still under construction - to prevent the inclusion of zero or negative values in the data set (21 observations have been removed from the database), the final dataset consisted of 4,293 observations. Additionally, the final sample included data from 188 charterers and 382 shipping owners. *Table 3-1* summarises the variables used in the analysis, as well as their interpretation and expected coefficients.

Table 3-1: Data descriptions and expected coefficients

Dependent Variable	Units	
Time Charter Rate	($/day)	
Independent Variables	**Units**	**Expected coefficients**
Macro variables		
China_PMI	China Manufacturing Purchasing Managers Index	+
Fuel_Price	Fuel price in the contracted date ($/day)	+/-
Charter period	The average period between the minimum and maximum contracted period (in months)	+
Idle	Idle containership capacity (% of the fleet)	-
Vessel characteristics		
TEU	Vessel capacity in TEU	+
$EEDI_{att}$	Attained values of the Energy Efficiency Design Index for existing ships (tones CO_2/ton-mile)	-
Age	Age of the vessel on the contracted period	-
Dummy eco	Dummy variable for vessels equipped with eco-engines	+

Following Table 3-1, variables indicative of market conditions were classified as macro variables, whereas those describing the ship were categorised as vessel characteristics. In this context, the energy efficiency of the vessels was measured by calculating the $EEDI_{att}$, (Eq. 3-1). The EEDI is a regulatory measure established by the IMO, designed to limit the

CO_2 emissions per ton-mile of new ships by setting energy efficiency standards. It is a technical metric that incorporates key parameters such as ship speed, deadweight tonnage (DWT), and specific fuel consumption (SFC) to assess a vessel's overall energy performance. Vessels with lower EEDI values are more energy-efficient, which is expected to positively influence their charter rates by making them more attractive to charterers looking for cost savings and regulatory compliance.

To avoid multicollinearity, variables such as vessel speed, DWT, and fuel consumption were not treated separately in the model, as these are already captured in the calculation of $EEDI_{att}$. Vessel size was measured in twenty-foot equivalent units (TEUs), a standardised metric for container ship capacity. TEU serves as a crucial determinant of a vessel's earning potential, as larger vessels benefit from economies of scale and can transport more cargo, which typically results in higher time-charter rates. Vessel capacity is thus positively correlated with time charter rates, as bigger vessels are more cost-efficient for charterers.

Vessel age is expected to have a negative coefficient, indicating that older vessels are associated with lower rates. As vessels age, they become less attractive in the market due to higher operational costs, lower efficiency, and increased maintenance needs. Consequently, older ships typically command lower charter rates than newer, more efficient vessels. This variable is included to account for the depreciation in vessel performance and its subsequent effect on time charter rates. For the age of the vessels, the approach involved adding one year to each vessel in the entire sample. This adjustment was made to prevent zero values in the model for vessels built and put into service within the same year.

Moreover, eco-engine ships were represented in the model by a dummy variable, taking the value of 1 when the vessel was equipped with an eco-engine and 0 otherwise. Eco-engines refer to vessels equipped with modern electronic main engines, offering significant improvements in fuel efficiency and emission reductions. These engines can reduce Specific Fuel Oil Consumption (SFOC) by approximately 2-2.5% at lower power levels compared to traditional engines, and they enable vessels to meet strict MARPOL Annexe VI Tier II NOx requirements by lowering NOx emissions by up to 30% under optimised operating conditions (Philip, 2016). Ships with eco-engines are increasingly preferred by charterers due to fuel cost savings, with charterers often willing to pay premiums for vessels that deliver long-term operational efficiencies and regulatory compliance (Dirzka and Acciaro, 2021). Including this variable helps capture whether these vessels command a premium, as their enhanced energy efficiency is expected to secure higher rates and longer contracts.

Continuing with the macroeconomic variables, the China Purchasing Manager's Index (PMI) was used as a proxy for market sentiment[7]. The PMI is an economic indicator derived from monthly surveys of private-sector companies, and it is a crucial tool for forecasting vital economic variables and is widely recognised as an indicator of economic trends (Shaikh, 2023). China PMI is a crucial economic indicator representing the health of China's manufacturing sector, which has a direct influence on global trade. Since China is both a leading exporter and importer, fluctuations in the China PMI have a significant impact on global shipping demand. A higher PMI suggests increased manufacturing activity and export volume, leading to heightened demand for containerships and, consequently, higher time charter rates. In addition, more traditional indices, such as the China Containerised Freight Index (CCFI) and the Shanghai Containerised Freight Index (SCFI), were not taken into consideration, as together with the time-charter rates, they reflect the market price, and as a result, the model would have endogeneity issues.

Furthermore, the length of the charter period plays a significant role in determining rates. The relationship between charter duration and rates is influenced by expectations of the spot rate market. For example, when future spot rate expectations are low, shipowners may seek longer contracts at current favourable terms. Conversely, shorter contracts may reflect short-term needs or uncertainty, potentially leading to different negotiated rates close to the spot rate at the time of the contract (Stopford, 2009). As indicated by Adland

[7] PMI is a composite index comprised of five seasonally adjusted diffusion indices: Employment, Inventories, New Orders, Supplier Deliveries, and Production within the manufacturing sector. By reflecting the current direction of economic activity, the PMI offers valuable insights for policymakers, investors, and business leaders, aiding in informed decision-making, and it plays a vital role in predicting GDP growth, assessing business confidence, and identifying potential turning points in the economy.

et al. (2017), longer contracts were associated with lower rates for Panamax and Handymax dry bulk size vessels, whereas the relationship was positive for Capesize. Overall, this relationship was not linear, indicating that the relationship between contract duration and time charter rates is influenced by market conditions such as freight market cycles and fuel prices. In the analysis, the contract duration is expressed in months. When the vessel had a flexible contract period, the average contracted period was calculated between the minimum and maximum duration.

Moreover, fuel expenses constitute one of the largest operating costs in the shipping industry. As fuel prices rise, charterers increasingly favour fuel-efficient vessels to minimise costs. Therefore, fluctuations in fuel prices have a direct impact on the demand for energy-efficient ships and their corresponding charter rates. Nevertheless, the relationship between fuel prices and time charter rates is not always clear. As indicated by Agnolucci et al., (2014) there was a positive relationship between fuel prices and charter rates, suggesting that in periods with high fuel prices, charterers are seeking to charter more energy-efficient vessels, and therefore, there may be a willingness to pay a premium for vessels that offer greater fuel savings. The demand for more energy-efficient vessels can raise their charter rates, while the fuel surcharges on cargo owners may help offset some of the fuel costs (Pagonis and Pentheroudakis, 2019). In contrast, ships with higher fuel consumption (shown by higher EEDI values) tend to attract lower rates, as charterers directly bear the extra fuel costs, making these vessels less appealing when fuel prices are high (Adland, Alger, et al., 2017). Regarding fuel prices, the average spot bunker prices were determined based on the Rotterdam and Singapore spot prices for very low sulfur fuel (VLSF) or heavy fuel oil (HFO), depending on the type of fuel consumed by the specific containership. It is important to note that while inflation can influence time-charter rates, inflationary pressures are already reflected in the fuel price variable, which captures significant operational costs in the maritime sector. Moreover, since Clarkson provides information usually every week, the date of different variables was matched to the closest observation (contract) date.

Finally, in the model, the idle % of the total container fleet number was used to represent the available supply in the market. This variable helps explain the market balance between supply and demand and its effect on charter pricing. A negative correlation is anticipated between idle capacity and time-charter rates, implying that shipowners may obtain lower time-charter rates during market downturns or periods of oversupply.

For the energy efficiency index, the methodology from van Hassel (2017) was followed by calculating the following equation (Eq. 3-1) for the attained values of the EEDI. Similar to Agnolucci et al. (2014) and Adland et al. (2017), the $EEDI_{att}$ is conceptually equivalent to the EEDI outlined by the IMO (2010). However, while the IMO's EEDI applies solely to new vessels built after 2013, the same approach extends to older ships through EEXI, which is empirically estimated by the same EEDIatt values (Eq. 3. 1). The $EEDI_{att}$ in this study is calculated at the design stage in accordance with paragraph 2 of the '2018 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index ($EEDI_{att}$) for New Ships', (IMO, 2018). Given the limitations of available data and the absence of EEDI values for some vessels, this methodology provides a uniform and consistent calculation framework for the entire dataset.

$$EEDI_{att} = \mathrm{Cf} * \frac{(190 * 75\%Pb + 215 * PAE)}{fv * DWT * Vref} \qquad \textit{Eq. 3-1}$$

Where the $EEDI_{att}$ are the attained values of the EEDI (in g-CO_2/tonne-mile). Key variables of this formula include the Maximum Continuous Rating (MCR) of the ship's main engines (Pb) and the power of auxiliary engines (PAE), both in kilowatts (kW), reflecting the vessel's operational power. Due to limited data on auxiliary engine power (PAE) across all vessels, a similar approach to that of Kim et al., 2023 was applied. This involved calculating 5% of the main engine power at MCR conditions (P_{MCR}) for engines with a P_{MCR} greater than 10 MW, and 2.5% of P_{MCR} plus 250 kW for engines below this threshold. The Specific Fuel

Consumption (SFC) in grams per kilowatt-hour (g/kWh) measures fuel efficiency for each individual vessel, while the CO_2 content factor (Cf) relates to fuel consumption, expressed in tonnes of CO_2 per tonne of fuel (e.g., Heavy Fuel Oil (HFO) or Very Low Sulphur Oil (VLS)). In cases where ships were equipped with dual-fuel engines and capable of operating on lower CO_2 content fuels (e.g., LNG-capable vessels), the largest Cf value was considered. This assumed the vessel was still operating on Heavy Fuel Oil (HFO) or Very Low Sulphur Fuel Oil (VLSFO). The vessel factor (fv) is a numerical value that adjusts the formula for different types of vessels, with fv = 0.70 for containerships, reflecting variations in operational and design efficiency. The vessel's Deadweight Tonnage (DWT) represents the ship's carrying capacity in tonnes. Lastly, the Vref is the reference speed in knots, reflecting the vessel's capabilities at 75% of the main engine brake power (Pb). Vref is computed based on the formula in Eq. 3-2, which is derived from the Admiralty Constant (Wartsila, n.d.). Because the displacement of the vessel can be assumed to be constant and the MCR and the design speed are known, the reference speed at 75% MCR can be computed.

$$\mathrm{P} = \frac{V^3 . \Delta^{2/3}}{C_{ad}} \rightarrow \; V_{ref} = V_{Design.} \sqrt[3]{\frac{75\%MCR}{85\%MCR}} \qquad \textit{Eq. 3-2}$$

For the EEDI calculation, the vessel-specific characteristics (such as fuel consumption, engine power, DWT, and vessel speed) were retrieved from Alphaliner and matched with the vessel's IMO number to ensure accuracy (Alphaliner, 2024).

3.3.2 Regression Model Selection

Following a similar methodology to Adland et al. (2017), the estimation of the different variables on the time charter rates was performed using the regression model:

$$ln(TCit) = \beta 0 + \beta 1 * ln(PMI_t) + \beta 2 * ln\left(Fuel_{Prices_{it}}\right) + \beta 3 * ln\left(Charter_{Period_{it}}\right) + \beta 4 * ln(IDLE_t) + \beta 5 * ln(TEU_i) + \beta 6 * ln(EEDIatt_{it}) + \beta 7 * ln(AGE_{it}) + \beta 8 * D_{ECO} + c_i + u_{it} \qquad Eq.\ 3\text{-}3$$

Where:

- ln (TC_{it}) represents the logarithmic transformation of the time-charter rate for vessel *i* at time *t*.
- βo is the intercept.
- β_1 ,,β_2 ,β_3,... signify the coefficients for the independent variables.
- ln(PMI_{it}) refers to the logarithmic transformation of the China Manufacturing Purchasing Managers Index at time t
- ln($Fuel\_Prices_{it}$) indicates the logarithmic transformation of the average fuel price between Singapore and Rotterdam in the contracted date, for either intermediate (IFO) or heavy fuel oil (HFO)
- ln($Charter\_period_{it}$) corresponds to the logarithmic transformation of the mean contracted period for vessel i at time t
- ln($IDLE_{it}$) reflects the logarithmic transformation of the container vessels idle as % of the global fleet at time *t*.
- ln(TEU_{it}) expresses the logarithmic transformation of the cargo capacity in Twenty-foot Equivalent Units for vessel i at time t

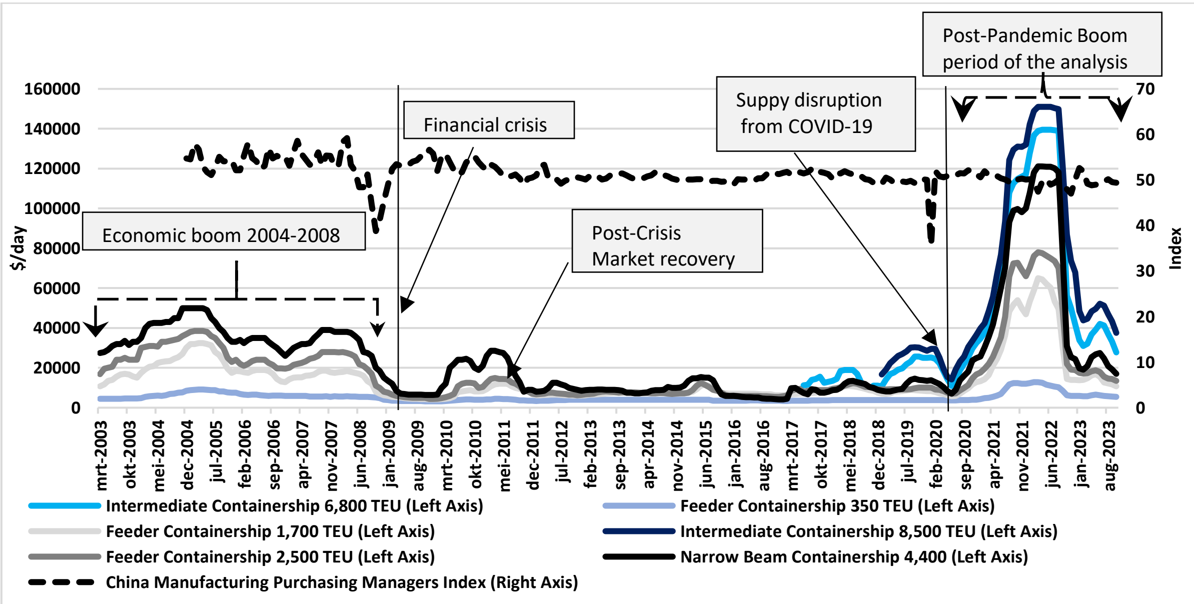
- $\ln(EEDIatt_{it})$ corresponds the logarithmic transformation of the attained Energy Efficiency Design Index of vessel *i* at time *t*.
- $\ln(Age_{it})$ represents the logarithmic transformation for the age of vessel *i* at time *t*.
- D_{eco}: a binary variable representing eco-engine vessels, assigned a value of 1 for eco-engine classification and 0 otherwise.
- c_i is the individual effect or individual heterogeneity.
- u_{it} the idiosyncratic errors

To estimate the model in Eq. 3-3, panel data regression techniques were performed using the random effects (RE) model. The rationale is that pooled ordinary least squares and fixed effect (FE) estimations do not account for the individual heterogeneity for ships that is constant over time. The RE model assumes that individual differences are random and uncorrelated with the predictors, allowing the analysis of both time-varying and time-invariant influences on the dependent variable. However, a drawback of the model is the assumption that the individual unobserved heterogeneity is not correlated with the error term (Wooldridge, 2010). In the model, all variables were transformed into logs for two reasons. Firstly, log transformations can reduce the influence of outliers, making the model more robust and less sensitive to extreme values, while they also help to capture proportional changes and multiplicative effects. Secondly, all variables provide a better fit in the model (higher R^2), indicating a stronger explanatory power of the model, and better Durbin-Watson statistics for autocorrelation, meaning the errors are more independent, thereby enhancing the reliability of the analysis (Greene, 2018). Finally, in all the regression models, white diagonal cluster-robust standard error estimations (White, 1980) were used to control potential heteroscedasticity and serial correlation, while the variance inflation factor (VIF) was used to check the multicollinearity.

3.4 Data Visualisation

This section provides an overview of the container liner shipping market, focusing on time charter rates differentiated by vessel size, as well as descriptive statistics on the dataset and empirical results from the regression models. Figure 3.2 illustrates the time charter rates for different vessel sizes (in $/day), as well as the China Manufacturing Purchasing Managers Index from March 2003 to October 2023.

Figure 3.2: Time-charter rates and PMI index for containers over the period 2003 – 2023

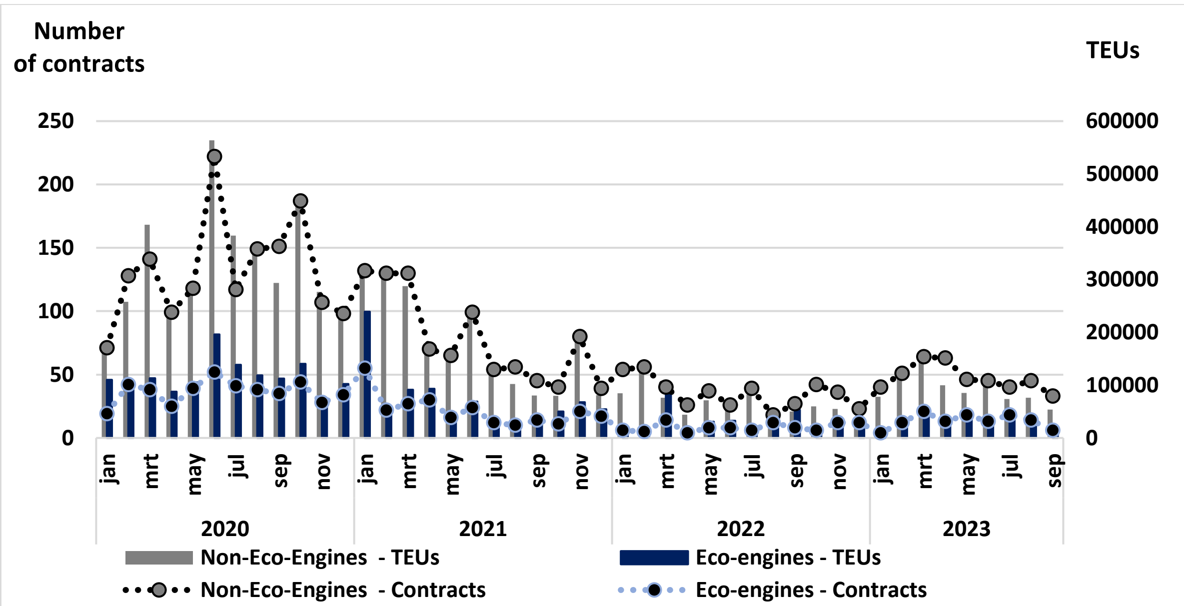


Source: Own compilation based on Clarkson Research NV (2024)

As can be seen, the dynamics of time charter rates in the container liner shipping industry have been influenced by global economic shifts. From 2004 to 2008, during China's economic boom, rates fluctuated with high volatility, while significant shifts occurred from 2020 to 2023 due to IMO decarbonisation targets and post-pandemic conditions. A 10% drop in container trade in Q2 2020 led to a market impact, but by September 2020, the charter rate index rose by 54%. This upward trend continued into 2021. However, rates fell in 2022 due to economic pressures, inflation, and high retail inventories, with a 60% drop by September 2022, though still above pre-COVID levels. (Clarksons research, 2020; 2022; 2023).

Figure 3.3 shows the number and capacity (in TEU) of contracts from January 2020 to September 2023 for eco-engine and non-eco-engine containerships. After COVID-19 supply disruptions, the time-charter market for containerships, led by non-eco-engine vessels, surged till October 2021. In 2020, there were 2,023 contracts (5.2 million TEUs) split between non-eco (1,588 contracts, 3.8 million TEUs) and eco-engine ships (435 contracts, 1.3 million TEUs). In 2021, the market remained active with 1,199 contracts (3 million TEUs) divided between non-eco (940 contracts, 2.2 million TEUs) and eco-engine ships (259 contracts, 0.87 million TEUs). However, after 2021, the market declined, with minor peaks in March 2023.

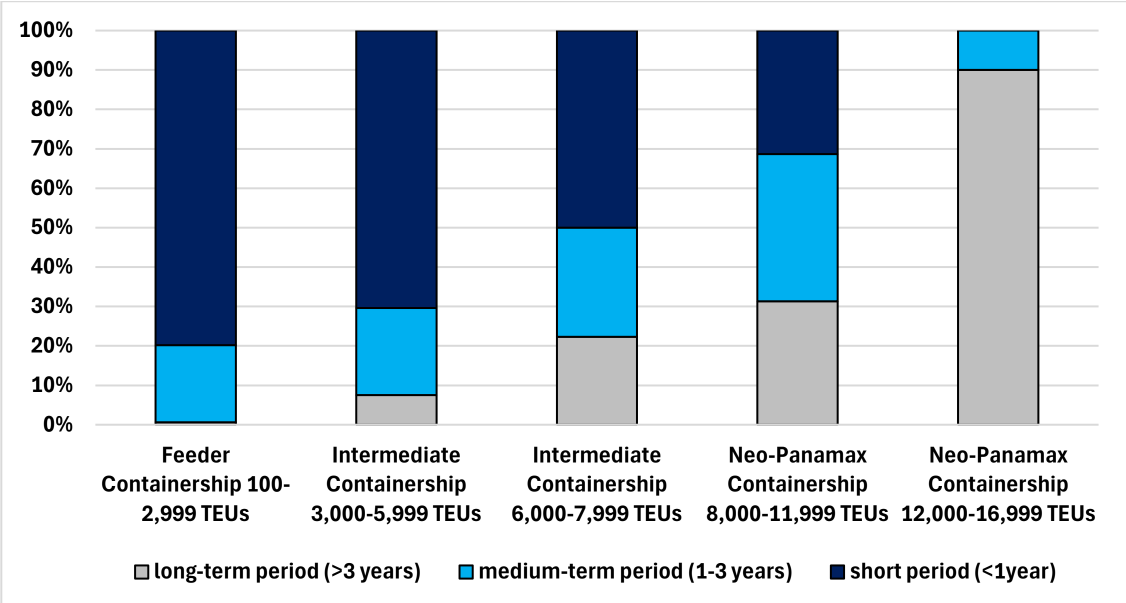
Figure 3.3: Time charter contracts for eco-engines and non-eco-engines containerships



Source: Own compilation based on Clarkson Research NV (2024)

Similarly, Figure 3.4 shows the distribution of time-charter durations across vessel size classes, indicating that small feeder containerships are mainly time-chartered under short-term agreements, with nearly 80% of agreements lasting less than one year. Medium-term agreements of 1 - 3 years are more common among feeder and intermediate vessels, while long-term contracts are largely concentrated in the largest containerships (12,000–16,999 TEU).

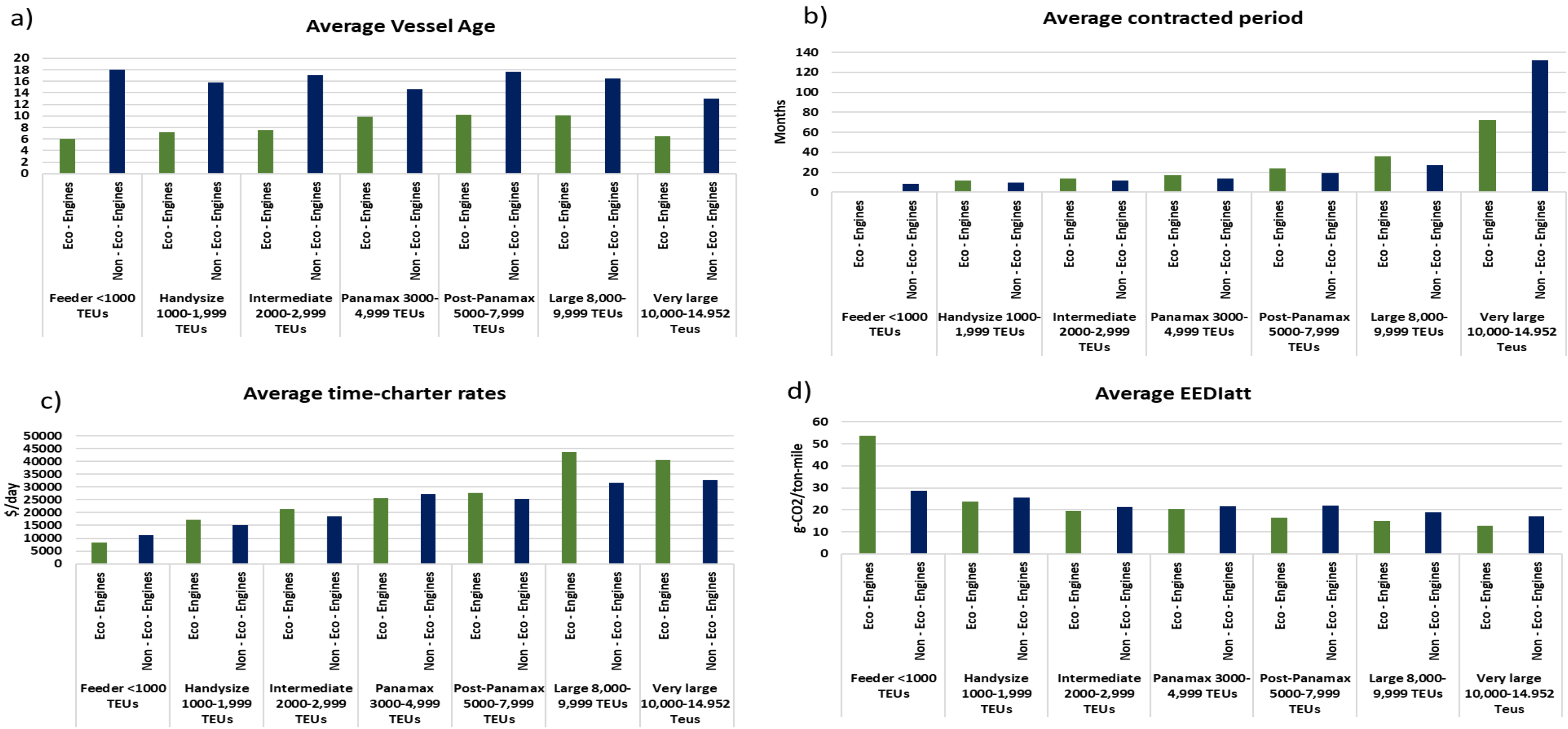
Figure *3.4*: Distribution of time-charter durations across different container vessel size classes



Source: Own compilation based on Clarkson Research NV (2024)

Figure 3.5 presents the descriptive statistics for key variables such as the time-charter period, vessel age, $EEDI_{att}$, and the mean contracted period, with the sample segmented by vessel size (ranging from feeder container ships under 1,000 TEUs to those up to 14,952 TEUs). It can be observed that as vessel size increases, both time-charter rates and the duration of the contract also increase across the two distinct types of containerships (eco-engine and non-eco-engine). Vessels equipped with eco-engines are generally younger, have higher time-charter rates, and have longer contracted periods. An exception was observed in the very large containerships (+14,000 TEUs) due to the limited number of observations (only 1 observation was indicated as a non-eco-engine containership compared to 25 eco-engine vessels). It is also noteworthy that eco-engine types are mainly used for bigger vessels rather than smaller ones, a trend linked to the market introduction of larger vessels after 2008 (Georgoudakis et al., 2023). This period marked a strategic shift in the maritime industry towards adopting more advanced, fuel-efficient technologies, while smaller vessels still in service often use older engine types. Furthermore, the analysis indicates that larger ships benefiting from economies of scale show lower $EEDI_{att}$ values, especially evident in eco-engine-equipped containerships, highlighting the impact of vessel size and technology on energy efficiency. Similar to the very large containerships, an unexpected pattern is observed with smaller feeder vessels, particularly eco-engine types, due to the limited sample size (only 2 observations were indicated as eco-engines compared to 647 non-eco-engines containerships), making it difficult to draw reliable conclusions about the relationship for the EEDIatt between eco-engines and non-eco-engines containerships.

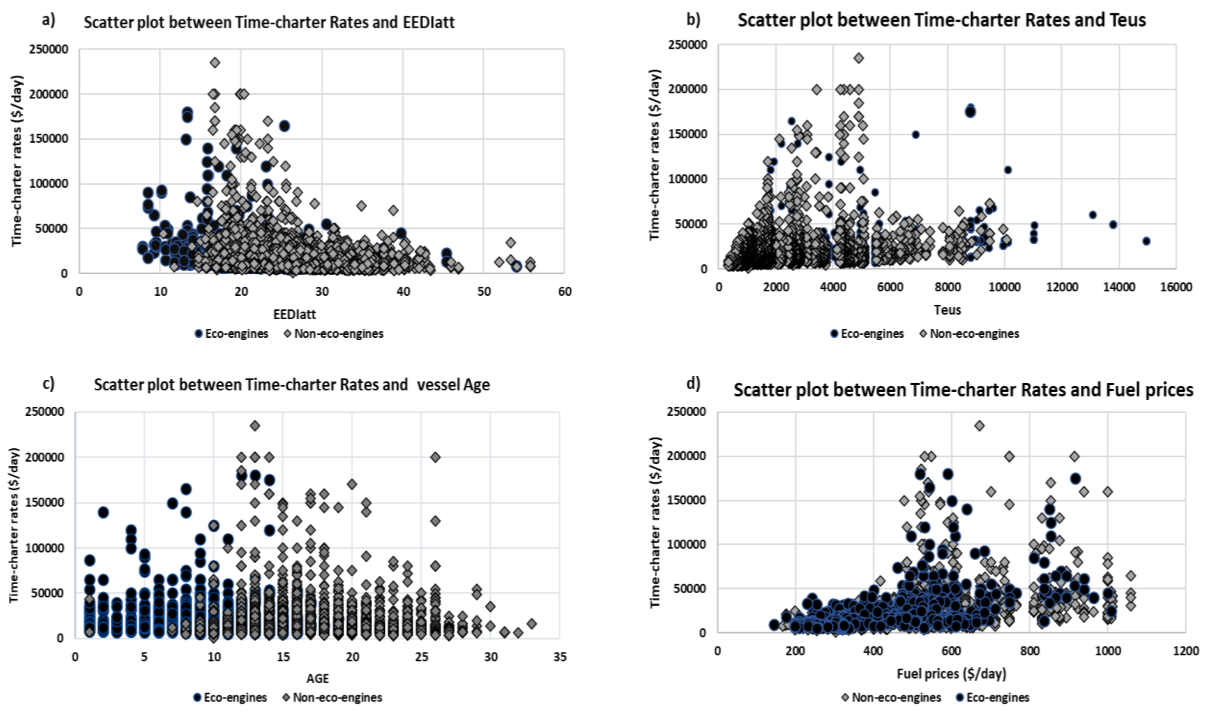
Figure 3.5: Descriptive statistics



Source: *Own compilation based on Clarkson Research NV (2024)*

Figure 3.6 presents four graphs related to the time-charter rates and the different variables, including the attained values of the EEDI$_{att}$ (graph a), vessel capacity in TEUs (graph b), vessel age (graph c), and fuel prices (graph d). The graphs also present the sample observations, distinguished into eco-engine and non-eco-engine ships. Concerning graph (a), it can be observed that there is a negative relation between the energy efficiency of the vessel and the time charter rates, indicating that less energy efficient containerships (Higher EEDI$_{att}$) gain lower time charter rates. Moreover, the vessel capacity (graph b) indicates a positive relationship, suggesting that bigger vessels are associated with higher rates. In contrast, the positive relation of the fuel price (graph d) suggests that as the fuel prices grow due to market inflations and other impacts, the time charter rates are also increasing, even though the operational costs are mainly on the charterers' account. Finally, regarding the relationship between vessel age and time charter rates (graph c), the observation is less clear, with a tendency of a negative relationship, meaning that as the vessel age increases, the time charter rates decrease.

Figure 3.6: Graphic representation of the EEDI$_{att}$, the vessel age, fuel prices, and vessel capacity to the time charter rates



Source: Own compilation based on Clarkson Research NV (2024)

Overall, this section highlighted that from 2020 to 2023, there were significant shifts in time charter rates. Descriptive statistics indicated that larger vessels exhibited higher time charter rates and longer contracted periods, while smaller vessels presented higher contract numbers but shorter durations. Furthermore, it was noted that, on average, eco-engine vessels commanded higher rates and demonstrated lower Energy Efficiency Design Index ($EEDI_{att}$) values, underscoring the increasing importance of sustainability in the shipping industry.

3.5 Empirical Results

Table 3-2 presents the results for four distinct regression models. Models 1 and 2 incorporate variables as described in Table 1, with Model 2 additionally incorporating a dummy-eco variable for vessels indicated as eco-engine containerships. For Models 3 and Model 4, dummy variables were introduced to control the time-specific effects. The inclusion of these dummy variables helps to account for the unique characteristics of specific periods, thereby improving the model's accuracy and reducing potential biases. The selected periods for the time-fixed effect were based on the sample observation and were distinguished into Pre-COVID-19 and recovery periods (January 2020 – May-2021), the Peak-period (June 2021 – August 2022), and the Post-Covid-19 period (September 2022- September 2023) as a reference point (see Appendix A)

Table 3-2: Empirical results from the regression models

Dependent variable ln(TC)				
	Regression Model 1	**Regression Model 2**	**Regression Model 3**	**Regression Model 4**
<u>Macro variables</u>				
	0.798	0.800	0.327	0.330
ln(PMI)	*0.064*	0.065	0.051	*0.051*
	(0.000)	(0.000)	(0.000)	(0.000)
	0.987	0.984	0.516	0.514
ln(Fuel_Price)	*0.029*	0.029	0.029	*0.029*
	(0.000)	(0.000)	(0.000)	(0.000)
	0.076	0.075	0.028	0.028
ln(Charter_Period)	*0.008*	0.008	0.007	*0.007*
	(0.000)	(0.000)	(0.000)	(0.000)
	-0.457	-0.457	-0.539	-0.539
ln(IDLE)	*0.027*	0.027	0.022	*0.022*
	(0.000)	(0.000)	(0.000)	(0.000)
<u>Vessel characteristics</u>				
	0.465	0.461	0.486	0.482
ln(TEU)	*0.013*	0.014	0.012	*0.013*
	(0.000)	(0.000)	(0.000)	(0.000)
	-0.120	-0.116	-0.099	-0.094
ln(EEDI)	0.033	0.033	0.027	*0.027*
	(0.000)	(0.000)	(0.000)	(0.000)
	-0.075	-0.053	-0.085	-0.059
ln(AGE)	*0.014*	0.017	0.010	*0.013*
	(0.000)	(0.003)	(0.000)	(0.000)
		0.046		0.054
D_{eco}		0.022		*0.019*
		(0.040)		(0.006)
<u>Controlling variables</u>				
Dummy-Pre-COVID-19 and			-0.025	-0.022
Recovery			0.015	*0.015*
			(0.094)	(0.129)
			0.676	0.678
Dummy-Peak- Period			*0.019*	*0.019*
			(0.000)	(0.000)
	-1.914	-1.959	2.688	2.622
Constant	*0.467*	0.465	*0.414*	*0.413*
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.673	0.674	0.787	0.788
Mean VIF	2.204	2.268	2.760	2.783
Number of observations	4,293	4,293	4,293	4,293

Source: Own compilation based on Clarkson Research NV (2024)

Values in italics are the standard errors. Values in (.) are the Probability values

Starting with the macro variables in Model 1, it can be observed that the China PMI, fuel prices, and the charter period have a positive impact on the time-charter rates, while idle capacity is negatively related to the time-charter rates. More specifically, the positive impact of the China PMI suggests that when there is a positive market expectation, a 1% increase can result in a 0.79% increase in time-charter contracts. Additionally, fuel prices are positively correlated with time-charter rates, with a 1% rise in fuel prices correlating with an approximate 0.98% increase in time-charter rates. This positive impact was also indicated by Agnolucci et al. (2014), suggesting that in markets with high volatility, an increase in fuel prices leads charterers to prefer more energy-efficient vessels at higher time-charter rates. At the same time, the positive impact of fuel prices and time-charter rates can be attributed to the fact that fuel costs are often passed on to the cargo owner. As a result, the charterer may hire a vessel at a higher rate regardless of fuel prices (Pagonis and Pentheroudakis, 2019). The duration of the contract was also positive, suggesting that when there is a 1% increase in the time-charter durations, there are 0.07% higher time-charter earnings. Lastly, the idle fleet percentage negatively affects rates, where a 1% increase in idleness leads to a 0.45% reduction in rates, indicating that during a market with oversupply, shipowners may be willing to negotiate lower time-charter rates.

Regarding vessel characteristics, $EEDI_{att}$ shows that less efficient vessels (those with higher EEDIatt values) correspond to lower rates, with a 1% decrease in EEDIatt leading to a 0.12% increase in the time-charter rate. The analysis also reveals that vessel capacity has a positive influence on time-charter rates. Specifically, a 1% increase in vessel capacity results in a rate increase of approximately 0.46%. On the other hand, the negative coefficient of the vessel age shows that older vessels obtain lower time-charter contracts, with a 1% increase in the vessel's age resulting in 0.07% lower rates. Similar results were observed in Model 2, with the only exception that this model includes a dummy variable for eco-engine containerships (D_{eco}). The positive coefficient of the D_{eco} further suggests a rate premium for eco-engine vessels. The coefficient of 0.04 for the dummy variable in the log-linear model suggests that eco-engine containerships are associated with approximately a 4.08% increase in the time-charter rates[8].

[8] The coefficient of 0.04 translates to approximately a 4.08% increase in the dependent variable (time-charter rates) when the dummy variable is present. This is calculated as (e0.04-1)*100 = 4.08%

In Models 3 and 4, the inclusion of dummy variables for specific periods, such as the pre-COVID-19 recovery and peak periods, further refines the analysis from Models 1 and 2, respectively. The dummy for peak periods is highly significant, with a positive impact on time-charter rates, reconfirming that time-charter rates were substantially higher during these times. The dummy for the pre-COVID-19 and recovery period, while negative, is not statistically significant, suggesting that these periods do not drastically affect the rates after controlling for other variables. The reduction in the coefficients for fuel prices and the PMI when including these dummy variables indicates that some of the effects previously attributed to these macroeconomic factors are due to time-specific influences. By incorporating dummy variables for specific periods, the models better isolate the impacts of fuel prices and PMI, revealing that a portion of their initial influence was capturing unique characteristics of certain periods, such as economic cycles or market conditions. Overall, the improved R^2 values in Models 3 and 4 (0.787 and 0.788, respectively) demonstrate that including period-specific dummy variables enhances the model fit, providing a more accurate representation of the factors influencing time-charter rates. Lastly, the mean VIF values indicate that multicollinearity is not a significant issue, ensuring the reliability of the regression coefficients (for more details, see Appendix B).

To re-evaluate the results and understand the differences between container ships equipped with eco-engines and those with non-eco engines, Table 3 presents outcomes from two distinct models for these two categories.

Table 3-3: Empirical results from the regression models for the eco and non-eco engines

Dependent variable ln(TC)				
	Eco - Engines		**Non - Eco - Engines**	
	Regression Model 1	**Regression Model 2**	**Regression Model 1**	**Regression Model 2**
Macro variables				
ln(PMI)	0.696 *0.134* (0.000)	0.270 *0.115* (0.020)	0.832 *0.074* (0.000)	0.341 *0.057* (0.000)
ln(Fuel_Price)	0.812 *0.064* (0.000)	0.408 *0.064* (0.000)	1.029 *0.033* (0.000)	0.537 *0.032* (0.000)
ln(Charter_Period)	0.094 *0.018* (0.000)	0.039 *0.016* (0.013)	0.069 *0.008* (0.000)	0.026 *0.007* (0.000)
ln(IDLE)	-0.452 *0.054* (0.000)	-0.567 *0.046* (0.000)	-0.464 *0.031* (0.000)	-0.534 *0.024* (0.000)
Vessel characteristics				
ln(TEU)	0.395 *0.039* (0.000)	0.400 *0.033* (0.000)	0.473 *0.015* (0.000)	0.492 *0.014* (0.000)
ln(EEDI)	-0.208 0.081 (0.010)	-0.181 *0.058* (0.002)	-0.113 *0.036* (0.000)	-0.123 *0.032* (0.000)
ln(AGE)	-0.033 *0.024* (0.016)	-0.055 *0.016* (0.000)	-0.061 *0.033* (0.061)	-0.043 *0.028* (0.145)
Controlling variables				
Dummy-Pre-COVID-19		0.067 *0.031* *(0.033)*		-0.043 *0.017* (0.011)
Dummy-Market boom and recession		0.706 *0.045* (0.000)		0.674 *0.021* (0.000)
Constant	0.246 *1.028* (0.810)	4.412 0.894 (0.000)	-2.402 *0.521* (0.000)	2.408 *0.475* (0.000)
R^2	0.650	0.767	0.672	0.790
Mean VIF	2.492	3.108	2.277	2.905
Number of observations	914	914	3,379	3,379

Source: Own compilation based on Clarkson Research NV (2024).

Values in italics are the standard errors. Values in (.) are the Probability values

Concerning the macroeconomic variables, it becomes evident that both eco-engine and non-eco-engine vessels respond positively to changes in China's PMI and fuel prices, with non-eco-engine vessels showing a stronger response. For example, a 1% increase in China PMI results in a 0.69% increase in time-charter rates for eco-engine vessels but leads to a 0.83% increase for non-eco vessels. This heightened sensitivity reflects the greater reliance of non-eco vessels on overall market demand and economic conditions. Similarly, fuel prices have a larger impact on non-eco vessels, where a 1% increase in fuel prices leads to a 1.02% increase in rates, compared to 0.81% for eco-engine vessels. This suggests that non-eco vessels, being less fuel-efficient, incur higher operational costs during periods of rising fuel prices, leading charterers to adjust rates accordingly.

Idle capacity negatively affects both types of vessels, with similar magnitudes across models. A 1% increase in idle fleet capacity reduces time-charter rates by approximately 0.45% for eco-engine vessels and 0.46% for non-eco vessels. This suggests that, regardless of fuel efficiency, an oversupply of vessels in the charter market drives down time-charter rates and reduces shipowners' bargaining power. As a result, shipowners become more flexible in offering terms to secure contracts, leading to increased competition in the market and potentially lower profitability.

Regarding vessel energy efficiency, for eco-engine vessels, a 1% increase in $EEDI_{att}$ leads to a 0.20% decrease in charter rates, while for non-eco vessels, the effect was less strong, with a 0.11% decrease in rates. This suggests that charterers value fuel efficiency more strongly in eco-engine vessels, as these are expected to provide higher energy savings. Consequently, when eco-engine vessels show improved energy efficiency, time-charter rates increase more sharply, reflecting the premium placed on their performance standards relative to less efficient, non-eco vessels.

Vessel capacity (TEU) positively affects rates across both categories, with non-eco vessels showing a higher response. For instance, a 1% increase in TEU leads to a 0.39% increase in charter rates for eco vessels, while it leads to a slightly higher 0.47% increase for non-eco vessels. This reflects that during the period of the analysis, charterers assigned greater value to larger non-eco vessels due to their carrying capacity, even though they may be less fuel-efficient. In addition, vessel age negatively impacts charter rates, particularly for non-eco-engine vessels, where older ships tend to receive lower time-charter earnings. For non-eco vessels, a 1% increase in age results in a 0.06% decrease in rates, while for eco vessels, the impact is less pronounced. This difference likely reflects the greater sensitivity of charterers to the age of non-eco vessels, as older, less efficient vessels become less competitive. In contrast, eco-vessels may retain more value over time due to their fuel-efficient technologies.

In Model 2, the introduction of dummy variables for market boom periods provides further clarity. Both eco and non-eco vessels experienced significantly higher time-charter rates during economic expansions, with the market boom dummy exhibiting strong positive coefficients in both models. However, the pre-COVID-19 dummy reveals a difference between the two categories: while eco-engine vessels experience a modest positive effect in relation to their reference point of the dummy-market boom and recession period, the non-eco vessels show a negative response, possibly reflecting the differing demand dynamics during this period. Overall, the results regarding the China PMI, $EEDI_{att}$, fuel prices, idle capacity, and TEUs were similar for both eco-engine and non-eco-engine vessels, showing positive signs for China PMI, TEU, and fuel prices, and negative for EEDIatt, idle capacity, and vessel age. Lastly, the mean VIF values indicate that multicollinearity is not a significant issue, ensuring the reliability of the regression coefficients (for more details, see Appendix C).

In addition to the random effect models, ridge regression was applied to address potential multicollinearity among the predictors and dummy variables (Table 3-4). Ridge regression, also known as Tikhonov regularisation (Tikhonov and Arsenin, 1977), is a technique used in statistical modelling and machine learning to mitigate collinearity in linear regression models. This method includes a regularisation parameter (λ) to prevent overfitting by adding a penalty to the size of the coefficients. This regression, with a regularisation parameter (lambda set at 0.02 in this case), imposes a small degree of shrinkage on the estimated coefficients. This penalisation shrinks the estimates of correlated predictors toward zero, thereby stabilising the coefficient values and reducing the sensitivity of the model to multicollinearity. It helps to stabilise the coefficients of correlated variables, providing a more reliable set of predictors (Hoerl and Kennard, 1981).

Table 3-4: Empirical results from the Ridge regression models

	Dependent variable ln(TC)			
	Ridge Regression Overall sample Lambda: 0.02	**Ridge Regression Overall sample Lambda: 0.02**	**Ridge Regression Eco – Engines Lambda: 0.02**	**Ridge Regression Non – Eco – Engines Lambda: 0.02**
Macro variables				
	0.312	0.318	0.258	0.333
ln(PMI)	*0.032*	*0.032*	*0.030*	*0.033*
	(1.222)	(1.222)	(1.247)	(1.216)
	0.492	0.490	0.381	0.514
ln(Fuel_Price)	*0.255*	*0.254*	*0.201*	*0.270*
	(2.940)	(2.942)	(2.841)	(2.978)
	0.026	0.026	0.040	0.022
ln(Charter_Period)	*0.042*	*0.041*	*0.069*	*0.003*
	(1.315)	(1.318)	(1.383)	(1.280)
	-0.534	-0.534	-0.547	-0.533
ln(IDLE)	*-0.237*	*-0.237*	*-0.260*	*-0.237*
	(2.029)	(2.029)	(2.020)	(2.033)
Vessel characteristics				
	0.482	0.479	0.389	0.491
ln(TEU)	*0.463*	*0.460*	*0.361*	*0.469*
	(1.455)	(1.472)	(1.947)	(1.358)
	-0.101	-0.098	-0.197	-0.121
ln(EEDI)	-0.036	-0.035	*-0.088*	*-0.021*
	(1.377)	(1.380)	(1.811)	(1.202)
	-0.090	-0.065	-0.057	-0.059
ln(AGE)	*-0.069*	*-0.050*	*-0,062*	*-0.021*
	(1.068)	(1.724)	(1.266)	(1.058)
		0.050		
D_{eco}		*0.030*		
		(1.709)		
Controlling variables				
Dummy-Pre-COVID-19	-0.053	-0.051	0.045	-0.076
and Recovery	*-0.037*	*-0.035*	*0.033*	-0.053
	(2.613)	(2.615)	(2.574)	(2.703)
Dummy-Peak- Period	0.662	0.661	0.688	0.656
	0.390	0.390	*0.418*	*0.391*
	(1.771)	(1.772)	(1.759)	(1.795)
R^2	0.789	0.789	0.768	0.791
Number of observations	4,293	4,293	914	3,379

Source: Own compilation based on Clarkson Research NV (2024). Values in italics are the standardized coefficients. Values in (.) is VIF values.

The results from the ridge regression confirmed the robustness of the findings from the random effects model, showing consistent significant effects of macro and vessel characteristics on time-charter rates. The macro variables, PMI and Fuel Price, positively impact time-charter rates across all samples, with unstandardized coefficients of around 0.312 and 0.492, respectively. This indicates that higher PMI and fuel prices are associated with higher time-charter rates, highlighting their critical role in market dynamics. The Idle variable consistently exhibited a negative effect, with an unstandardized coefficient of approximately -0.534, suggesting that increased idle capacity significantly reduces time-charter rates.

Among the vessel characteristics, TEU shows a strong influence on time-charter rates, with unstandardized coefficients ranging from 0.389 to 0.491. This indicates that larger vessel capacity is a key determinant of higher rates, despite the operational fuel efficiency. Conversely, $EEDI_{att}$ and vessel age presented negative effects across all samples, with unstandardized coefficients of about -0.10 for $EEDI_{att}$ and -0.09 for age, highlighting that decreased energy efficiency and increased vessel age are associated with lower charter rates. The sharper decrease in time-charter rates for eco-engine vessels as $EEDI_{att}$ increases highlights the premium placed on energy efficiency for these vessels, as charterers place greater value on the fuel-saving potential of eco-engine containerships. The pre-COVID-19 dummy variable had an unstandardized coefficient of around -0.053, indicating a reduction in rates compared to the reference period, while the peak period dummy had a significant positive effect with coefficients around 0.662, reflecting higher rates during peak times. In the eco-engine sample, the pre-COVID-19 dummy variable showed a positive coefficient of 0.045, contrasting with the negative coefficients observed in the overall and non-eco-engine samples and their reference points. This suggests that during the whole period of the analysis, eco-engine vessels were positively affected in terms of time-charter rates, likely due to their higher efficiency and greater market attractiveness, even during the pre-COVID period.

Finally, the R^2 values were robust, ranging from 0.768 to 0.791, indicating a good fit in the models and confirming the explanatory power of the selected variables. The consistency of standardised coefficients across different samples (overall, eco-engines, and non-eco-engines) further validates the model's reliability and the significance of the identified factors.

3.6 Discussion

Time-charter rates, which are crucial for the profitability of shipping companies and their investment decisions, have recently been influenced by various factors, including geopolitical events and economic pressures arising from COVID-19 supply chain disruptions. Additionally, the industry faces challenges from the IMO's ambitious goal to achieve emission neutrality by 2050, alongside the implementation of the Energy Efficiency Design Index (EEDI). These developments prompt a critical examination of whether investments in fuel-saving technologies and more energy-efficient vessels yield premiums for shipowners.

This research used individual fixtures over the period January 2020 to October 2023 and identified the key variables impacting the time-charter rates, while it used the attained values for the energy efficiency index ($EEDI_{att}$) as a measure to calculate the energy efficiency for containerships. A random effect regression model analysed the impact of these variables, and additional analysis was conducted by separating the sample into eco-engine and non-eco-engine container ships. To control potential time effects, dummy variables were included and distinguished into pre-COVID-19 and Recovery periods and a dummy for the Peak-Period, while the potential multicollinearity was controlled using the Ridge regression model.

The results revealed that more fuel-efficient and energy-efficient vessels gain premiums in their time-charter contracts, with a 1% decrease in $EEDI_{att}$ leading to a time-charter rate increase of 0.09% to 0.12%, evidenced by a negative impact of the $EEDI_{att}$ on time-charter rates as indicated in Table 2. The impact of the energy efficiency was even more evident for the eco-engines in Table 3, where a 1% decrease in the $EEDI_{att}$ led to a 0.18% to 0.20% increase in the time-charter contracts for these vessels, reflecting the premium placed on their performance standards. At the same time, the indication of eco-engine types also leads to higher and longer contracts, especially for larger containerships. A significant positive correlation between vessel capacity and time charter rates suggests that larger vessels are associated with higher time-charter rates. Furthermore, the positive correlation between the China PMI and time charter rates highlights the sensitivity of time-charter rates to market dynamics. As the PMI reflects overall economic health and market demand, its positive impact on time-charter rates suggests that higher market demand or expectations lead to an increased willingness among charterers to pay higher rates to charter a vessel. Additionally, the study suggests a positive relationship between fuel prices and an increased preference for more fuel-efficient, eco-engine vessels, indicating an emergent market incentive for investing in green and fuel-efficient technologies. However, this preference is not uniform across all charterers and is influenced by factors such as emission reduction targets, the length of cooperation between charterers and shipowners, and the duration of chartering periods. Some charterers may prioritise emission reductions in response to stricter regulations or to align with corporate sustainability targets (Raza, 2020; Rehmatulla and Smith, 2020), while others may be more influenced by immediate cost factors or shorter-term operations (Agnolucci et al., 2014; Adland, Alger, et al., 2017; Dirzka and Acciaro, 2021). The duration of cooperation and the length of chartering periods also affect preferences, with longer agreements providing more substantial incentives for adopting energy-efficient vessels due to potential fuel savings over time (Rehmatulla and Smith, 2020; Dirzka and Acciaro, 2021).

In this context, fuel costs, regulatory pressures, and the environmental consciousness of charterers drive the willingness to pay a premium for fuel-efficient and eco-engine vessels (Agnolucci et al., 2014; Adland, Alger, et al., 2017; Dirzka and Acciaro, 2021). Charterer-specific characteristics play a significant role in shaping freight rates, and their relationship with shipowners can have a strong impact on contract terms (Adland et al., 2016). Additionally, charterers with environmental commitments may be more inclined to offer a premium for vessels that align with sustainability goals (Rehmatulla and Smith, 2020; Dirzka and Acciaro, 2021) . At the same time, shipowners are encouraged to consider eco-friendly technologies as a strategic investment, as this can lead to higher charter rates and improved competitiveness, particularly in markets where charterers show a clear preference for fuel-efficient vessels (Adland, Alger, et al., 2017; Agnolucci et al., 2014; Dirzka and Acciaro, 2021).

Despite the importance of this essay, it comes with some limitations. One of the primary limitations pertains to the timeframe, which is constrained by the availability of historical data. Even though the data availability permits adequate interpretation of the results, the analysis covers the period from January 2020 through 2023. Furthermore, this study excludes the explicit analysis of the relationship between owners and charterers, though such relationships could have a substantial impact on how these preferences are negotiated on a case-by-case basis. Additionally, due to data constraints, the analysis does not delve into specific trade lane regions where containerships operate. A more extensive analysis for specific regions or trade lanes could provide better information regarding the operational aspects of the time charter market. Lastly, while IMO and EU continuously introduce measures aimed at decarbonising the sector, this research considers only the attained Energy Efficiency Design Index (EEDI) values as a measure.

3.7 Conclusions

This research study highlights the critical factors influencing time charter rates within the container liner shipping industry, demonstrating the significant impact of vessel capacity, fuel efficiency, and market demand dynamics. The research reveals that a 1% increase in energy efficiency leads to a time-charter rate increase of 0.10% to 0.12%. This effect was even more evident for the eco-engine containerships, where a 1% increase in energy efficiency leads to a 0.18% - 0.22% increase in their time-charter rates. Moreover, in the time-charter market, vessel capacity, market dynamics, and future expectations emerge as pivotal elements shaping negotiation strategies between shipowners and charterers. Notably, the distinction between eco-engine and non-eco-engine vessels is evident. As demonstrated in Table 3.2 and Table 3.4, eco-engine vessels command higher time-charter rates, as reflected by the positive impact of the eco-dummy variable, reflecting a growing market preference for environmentally sustainable shipping solutions.

However, preferences for fuel-efficient vessels may vary. While some charterers and shipowners have a stronger preference for more efficient vessels, their adoption and willingness to pay premiums for such vessels often depend on specific case-by-case factors. These include regulatory demands, the length of the chartering period, and the nature of cooperation between charterers and shipowners. Longer cooperation times or charter periods incentivise the selection of fuel-efficient vessels, as the benefits of reduced operational costs and regulatory compliance become more significant over time.

In the rapidly evolving container shipping market, vessel capacity and eco-friendly technologies have a significant impact on time-charter rates. Shipping companies must prioritize strategic fleet modernization to incorporate vessels that provide operational efficiencies. This entails not only a balanced approach to capacity management but also an investment in eco-friendly technologies to mitigate the effects of fuel prices and align with stricter emission regulations imposed by the IMO and other regulators. Companies that proactively adapt to these changes can better address regulatory challenges and appeal to charterers seeking sustainable shipping solutions.

Future research should further explore the long-term implications of these trends, particularly regarding the heterogeneous impacts of charterers' preferences for emission reduction, cooperation time between shipowners and charterers, and evolving regulatory frameworks. Moreover, a longer period of analysis could provide more insightful information regarding the key variables affecting time-charter rates. As vessels capable of operating with alternative fuels (such as LNG, biofuels, and ammonia) enter the market, future analysis should focus on how operating under these fuels impacts time-charter rates. Lastly, future research should examine how these factors influence shipowner-charterer relationships and whether different vessel sizes and submarkets are impacted differently. Finally, a more detailed analysis could encompass various vessel sizes, different submarkets, and geographical regions, as well as the interpretation of the charterer-owner relations and their position in the market.

Overall, this essay provides critical insights for shipowners, charterers, policymakers, and academics by identifying the determinants of time charter rates in maritime shipping. It highlights the importance of fuel efficiency in guiding strategic decisions and policy formulation. Additionally, it enriches academic discussions on maritime economics and environmental sustainability, supporting a broad spectrum of stakeholders in understanding and addressing the shipping industry's challenges.

Chapter 4: Essay 3 - Investment and Trading Strategies in the Maritime Sector: An Application to the Secondhand Containership Market[9]

As shipping market players operate in a competitive and volatile business environment, their highly capital-intensive investment decisions to target value-generating projects are exposed to critical risks. Therefore, this paper investigates the efficiency of investment strategies that combine technical trading rules and fundamental analysis in the sale and purchase of ships in the container shipping market. Using historical datasets of second-hand vessel prices and time-charter rates from October 1996 to June 2021, this study examines the long-run cointegrating implications and short-run causality spillover effects for three groups of containerships, distinguished by their transportation capacity, namely 725 TEUs, 1,700 TEUs, and 3,500 TEUs. In addition, the Moving Average trading rules are used to indicate the timing of investment or divestment decisions through the analysis period. The results for vessel prices and earnings for 3,500 TEU containerships appeared to be more volatile compared to smaller ships (725 TEUs and 1,700 TEUs), while time-charter earnings are seen to exert an impact on second-hand prices across all vessel types. Moreover, due to higher volatility, trading strategies based on price-earnings ratios significantly outperform buy-and-hold strategies for the 3,500 TEU and 1,700 TEU containerships. On the contrary, the decision to buy-and-hold smaller container ships (725 TEU) yields higher profits than the active sale and purchase strategy. The insights provided in this paper can be used by multiple stakeholders, such as liner operators, investors, lessors, and researchers.

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4.1 Introduction

As shipping market players operate in a competitive and volatile business environment, their highly capital-intensive investment decisions to target value-generating projects are exposed to critical risks. Moreover, new regulations imposed by the IMO towards decarbonisation and the green energy transition insert even more restrictions on maritime investments and the owner's operational decisions. Investment and trading strategies in the second-hand containership market have critical implications for shipping players due to market complexities, intense volatility dynamics, and multifaceted risk exposures in the shipping industry. Several studies investigated the impact of key drivers on investment decisions and company profitability by attempting to model a diverse set of critical factors, including freight rates, newbuilding contracts, deliveries, and scrapping rates (Standees, 1984; Tsolakis et al. 2003).

In the second-hand markets, several studies (Kavussanos, 1997; Merikas et al., 2008) have focused on pricing modeling and econometric analysis for different vessel types and sizes. Alizadeh and Nomikos (2007) develop an empirical technical analysis framework, employing the second-hand bulk shipping market's price-to-earnings (p/e) ratio to identify potential strategic investment opportunities. Following the cointegration relationship framework, the authors used the cointegration dynamics between (log) ship prices and (log) earnings, indicating potential long-run relationships between these series. They suggested that under efficient market conditions, the two spread series should be statistically equal, and could be incorporated to shape strategic investment decisions.

In the liner shipping market, empirical research has focused on pricing models, freight revenue drivers, and the differentiation between business segments. Moreover, much emphasis has been given to the development of vessel sizes, excess capacity, and cost reduction through economies of scale (Lim, 1998; Cullinane and Khanna, 2000; Sys et al., 2008). Other parameters, such as strategic actions based on environmental aspects and regulations, have also been part of the research topics. For example, Rau and Spinler (2016) account for endogenous prices, fuel-efficient investment, timing, and second-hand values, suggesting that alliances can stabilise capacity, while fuel-efficient ships are preferable for replacement in downturns and for expansion in upturns if they provide fuel savings of around 30%. Furthermore, it is suggested that, the second-hand prices and the sales volumes are impacted by freight rate level, age of the ship, inflation, and shipowners' future expectations (Alizadeh and Nomikos, 2006; 2007), with recent studies showing that greener vessels trade at roughly 20% higher prices compared to their conventional counterparts, reflecting the growing emphasis on energy efficiency and environmental performance (Jia et al., 2024).

Despite the extensive literature on investors' decision-making and operational strategies, the topic of exploiting potentially profitable opportunities arising from vessel trading in the sales and purchase (second-hand) ship market has not been adequately researched. In addition, much attention has been given to the big container vessels rather than smaller ship types. Examining these issues precisely indicates the novelty of the present research.

Therefore, this essay examines the performance of negotiation strategies based on technical trading rules and fundamental analysis in the second-hand container shipping market, giving attention to small and medium-sized container vessels. More specifically, the paper uses the historical data of second-hand vessel prices and time-charter rates from October 1996 to June 2021 for three container vessel sizes (725 TEU, 1,700 TEU, and 3,500 TEU). Following a similar approach to Alizadeh and Nomikos (2007) the present study tests the existence of a long-run cointegrating relationship and short-run causality between prices and earnings. This relationship is used as an indicator of investment or divestment timing decisions, utilising the moving average trading rules. Finally, the snooping data technique is also applied to re-evaluate the factual series results.

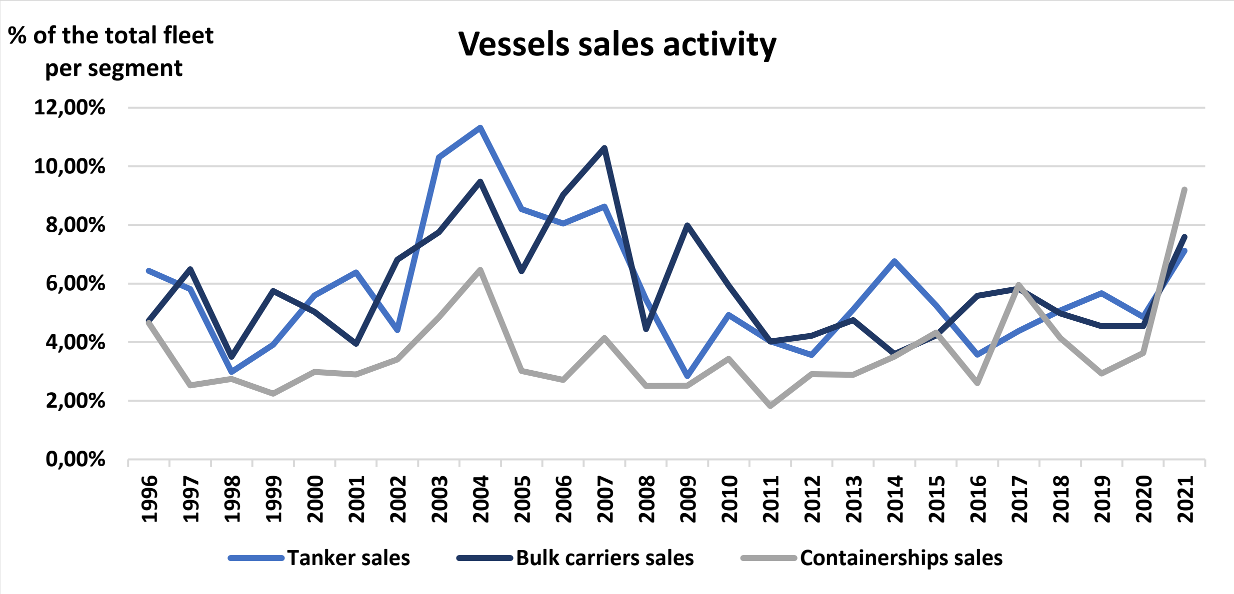
Essay 3is structured as follows. In Section 4.2, the essay presents a literature review of the sales and purchase shipping market, providing an overview of the containership market and fleet development for the analysis period. Section 4.3 presents the empirical results for the descriptive statistics and cointegration tests for three different container vessels, categorized by size (725 TEU, 1,700 TEU, and 3,500 TEU), traded on the second-hand shipping market. It also presents the Moving Average trading rules for those ships, while a bootstrap resampling technique is applied to re-evaluate the results from the original series. In Section 4.4, the essay provides a discussion and concludes.

4.2 Literature Review

The sales and purchase (S&P) market represents the place where the participants, who are commonly shippers, shipowners, and investors, negotiate second-hand vessels, and it is characterised as a market with high price volatility, where investors can achieve profits from the good timing of selling and purchasing activity, known as "asset play". In this market, the prices of vessels are negotiated between the buyer and the seller, while the timing and market conditions are the primary keys that influence trading effectiveness. For example, when the ship is sold at the bottom of the shipping cycle, it is a great bargain from the buyer's side, (Alizadeh, and Nomikos, 2007).

Furthermore, the sales and purchase market has a tenuous role. On the one hand, it is a market that involves a transaction between a shipowner and an investor, who is usually another shipping company, and for this reason, this transaction does not affect the cash held in the industry. On the other hand, in the newbuilding market, cash flows out of the shipping market, as shipyards use them to pay for materials, profits, and labour. The shipping market cycle is driven by those cash flows. At the beginning of the cycle, freight rates rise, and cash starts to be injected into the market, allowing the owners to pay higher prices for second-hand ships. The cash flows enable new investors to order new ships, as their prices appear more profitable. When the new ships are introduced into the market, the entire process reverses as freight rates reduce cash inflows, forcing investors to pay for the new ships. To meet their obligations, weaker owners are forced to sell their ships in the second-hand market, creating the ‘’asset play’’ in the market for the more prominent owners. One of the purposes of the maritime shipping cycle is to let out the inefficient companies and allow more efficient companies to enter the market. (Stopford, 2009).

Figure 4.1: Vessel sales volume for the tanker, bulk carrier, and container shipping industry



Source: Own compilation based on Clarkson Research NV (2021)

Figure 4.1 compares the vessel's sales activity for the tanker, bulk carrier, and container shipping industry from 1996 to 2021. It can be observed that different economic market conditions influence the vessel's sales volume. For example, during the financial boom period of 2002-2008, there was the highest activity in the sale volume of tankers and dry bulk ships, mainly driven by China's economic development, which led to freight rates reaching significant levels. However, the main reason for the high sales activity differed between the two segments.

For the tanker sector, 2002-2004 was a period when, after the “ERIKA” (1999) and “PRESTIGE” (2002) spill incidents, the IMO approved the “IMO Regulation 13G” (UNCTAD, 2004). The main guidelines of Regulation 13G were the phase-out of single tankers by 2010, the prohibition of Heavy Grade Oil (HGO) transportation by single-hull tankers, and the implementation of the Condition Assessment Scheme (CAS) for single-hull tankers over the next 15 years. New regulations, combined with high freight rates, led to new building orders and high demolition rates until 2004. In the second-hand market, the main interest was the sales for conversion purposes into dry bulk, FPOs, and heavy lift vessels (Clarksons Research, 2004 b).

In the dry bulk industry, as the world economy continued growing mainly due to Asian production and the burst of oil imports in China, the freight rates and interest rates remained at high levels, despite the recession in 2005 due to the impact of hurricanes on the US Gulf (Clarksons research, 2008b). During 2007, both the new building and second-hand sales markets were highly active, with freight rates being the main driver in all sectors and shipowners' earnings exceeding the long-term average. Moreover, in 2006, after an unexpected improvement in the demand for raw materials, mainly caused by Azerbaijan (its GDP had increased by 26%), and combined with the Olympic games conducted in China in 2008, shipowners were focused on second-hand dry bulk vessels, mainly due to extended delivery times for new buildings, and the high order book for the containership and tanker vessels in previous years (UNCTAD, 2008).

As also mentioned in the Essay 2.3.2 (see Figure 2.11), for the containership industry, the most imminent second-hand vessel sales were performed in 2020-2024 due to the supply chain disruption caused by COVID-19. The limitation in container tonnage availability due to scrubber retrofitting, combined with supply chain disruptions (port congestion, reduced service levels, and reliability) from COVID-19, had a significant impact on container trade volumes. By mid-April 2020, the SCFI had dropped by 19%, while from the start of 2020 till mid-June, the charter rates declined by 34% (Clarksons Research, 2021a). Between July and August 2020, demand for box trade experienced a significant improvement, and by September 2020, freight rates had returned to the same level as in March of the same year. At the start of September, the SCFI index was 24% higher than at the beginning of the year, driven by record gains in Transpacific spot freight. One supportive factor in the container industry was the sharp decline in bunker prices (around a 50% decrease), which allowed liner companies to report their best margins since 2010 in the second quarter. In 2021, as the world economy continued to grow, world GDP began to rebound in the second half of 2020 and had returned above pre-COVID levels by the second quarter of 2021 (Clarksons Research, 2021a). The period from 2020 to 2022 marked an exceptionally active phase for the industry, prompted by global supply chain disruptions, tightening environmental regulations from the IMO and EU decarbonisation targets, and geopolitical uncertainty. During this period, many shipowners temporarily idled vessels for retrofitting, maintenance, or repair, tightening fleet availability and contributing to a sharp rebound in charter demand, particularly in the time-charter segment (Clarkson's Research, 2023).

In the liner shipping market, empirical research has focused on pricing models, freight revenue drivers, and the differentiation between business segments, including the development of vessel sizes, excess capacity, and cost reduction through economies of scale (Lim, 1998; Cullinane and Khanna, 2000; Sys et al., 2008). Other parameters, such as strategic actions based on environmental aspects and regulations, have also been part of the research topics. Luo et al. (2009) applied a dynamic economic model in the container shipping industry to analyse the fluctuation of the freight rate between the demand for container transportation services and the capacity of the container fleet, concluding that the demand is derived from the global trade, and the fleet capacity was mainly increased from the orders in the profitable market conditions.

Furthermore, it is suggested that second-hand prices and the sales volumes are impacted by freight rate level, age of the ship, and shipowners' future expectations (Alizadeh and Nomikos, 2006; 2007). First, it is important to mention that despite the maritime sector's size and nature, the freight and time-charter rates are the primary factors influencing vessel prices and the order book. As freight rates are rising, there is a demand for new capacity in the market, which is affected by other factors such as the shipyard's available capacity, the long delivery time (up to 2-3 years), and the availability of the existing fleet capacity in the market (Ferrari et al., 2018). Secondly, the ship's age is another critical factor due to the depreciation in the vessel's value during its life (Alizadeh, and Nomikos, 2007). Thirdly, in the long term, ship prices are shaped by inflation, market volatility, and future expectations, with recent studies showing that greener vessels trade at roughly 20% higher prices compared to their conventional counterparts, reflecting the growing emphasis on energy efficiency and environmental performance (Jia et al., 2024).

Despite the extensive literature on investors' decision-making and operational strategies, the topic of exploiting potentially profitable opportunities arising from vessel trading in the sales and purchase (second-hand) ship market has not been adequately researched. In addition, the second-hand containership market remains predominantly composed of smaller containerships, including Feeder Containerships and Intermediate Containerships (see Figure 2.12 and Figure 2.13), highlighting their important role in the second-hand market. Therefore, examining these issues is essential for investment strategies and decision-making for shipowners and investors.

4.3 Empirical Analysis

Given the purpose of this essay, three different ship types traded on the second-hand market are evaluated. Next, the relationship between their prices and revenues is estimated as an indicator of the company’s profitability. The container ship sizes were selected based on the ship's contribution to the world market, as stated in Essay 2.3.2, allowing for the examination of any differences in the alternative ship sizes.

4.3.1 Data Description

For this Essay, monthly prices for 5-year-old ships are collected for three different container vessels (725 TEU, 1,700 TEU, and 3,500 TEU) from Clarkson’s Shipping Intelligence Network from October 1996 to June 2021. All prices are indicated in million dollars and represent the average value of vessels traded in each category in any specific month (Table 4-1). Moreover, in the shipping sector, operating profits can be defined as time-charter rates (Alizadeh and Nomikos 2007)

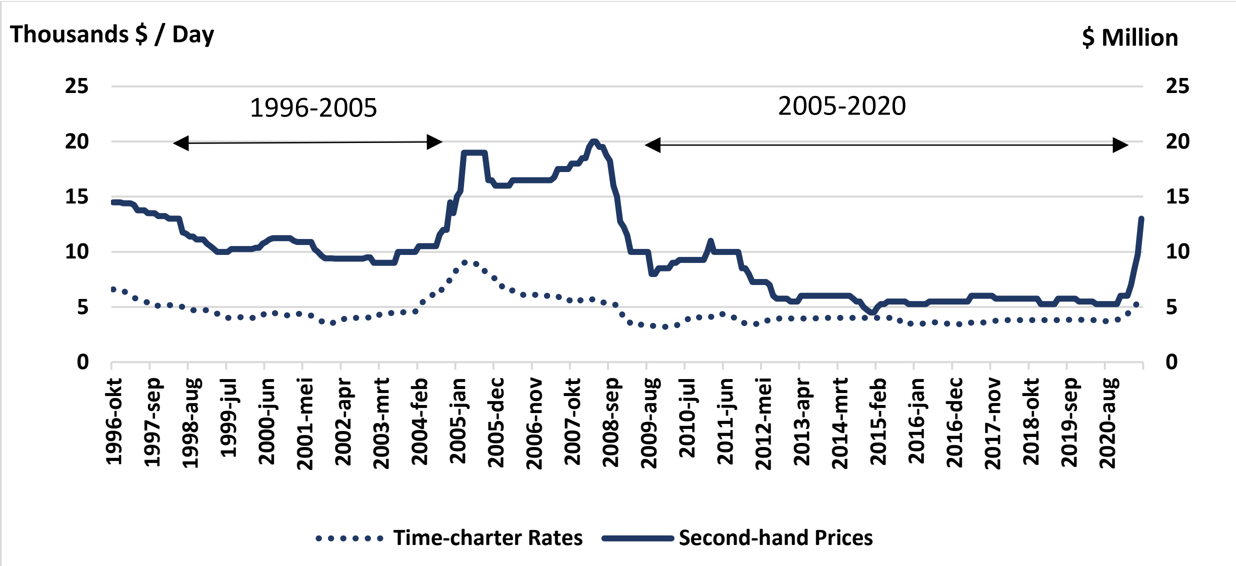
Table 4-1: Data description for the case study

Container shipping market			
Period	**October 1996 to June 2021**		
Vessels Prices	Containership 725 TEU 5yr old Second-hand Prices -$Million	Containership 1,700 TEU 5yr old Second-hand Prices -$Million	Containership 3,500 TEU 5yr old Second-hand Prices -$Million
Time-charter earnings	Feeder Containership 725 TEU 6-12 Month Time-charter Rates - $/DAY	Feeder Containership 1,700 TEU 6-12 Month Timecharter Rate - $/DAY	Narrow Beam Containership 3,500 TEU 6-12 Month Timecharter Rate – $/DAY

For the study, time-charter rates are used as a proxy for earnings for two reasons. First, time-charter rates represent the net earnings from the chartering activities of the vessel and do not include voyage costs. Second, since time-charter rates are hired contracts for several consecutive periods, they are considered to contain information about the future earnings of the vessel during these periods (Alizadeh and Nomikos, 2007). As a result, it is proposed that earnings from time-charter rates may explain price changes better than current spot rates. Monthly time-charter rates for (725 TEU, 1,700 TEU, and 3,500 TEU) vessels were also obtained from Clarkson's Shipping Intelligence Network for the same period.

Figure 4.2 presents the time-charter earnings and the second-hand prices for the 725 TEU containerships from October 1996 to June 2021. The graph categorises two main periods: from 1996, there is an upturn in the market, with a high peak for the time-charter rates in 2005, and thereafter, there is a market downturn until 2020. From 2021, the market tends to recover again. It can be observed that, while the time-charter earnings move in tandem with second-hand prices during the period of this study, under different market conditions, they tend to fluctuate. For example, in the recovering years between 2002-2005 and 2012-2015, the spread between the prices and the earnings keen to narrow, while on the other hand, in the market’s downturns, for example, the years 1996-2004, 2005-2008 and 2015-2019, this spread keen to wide, which indicates the relationship between those series. Moreover, it can be observed that from 2004 to 2008, second-hand prices reached their highest values for the entire study period.

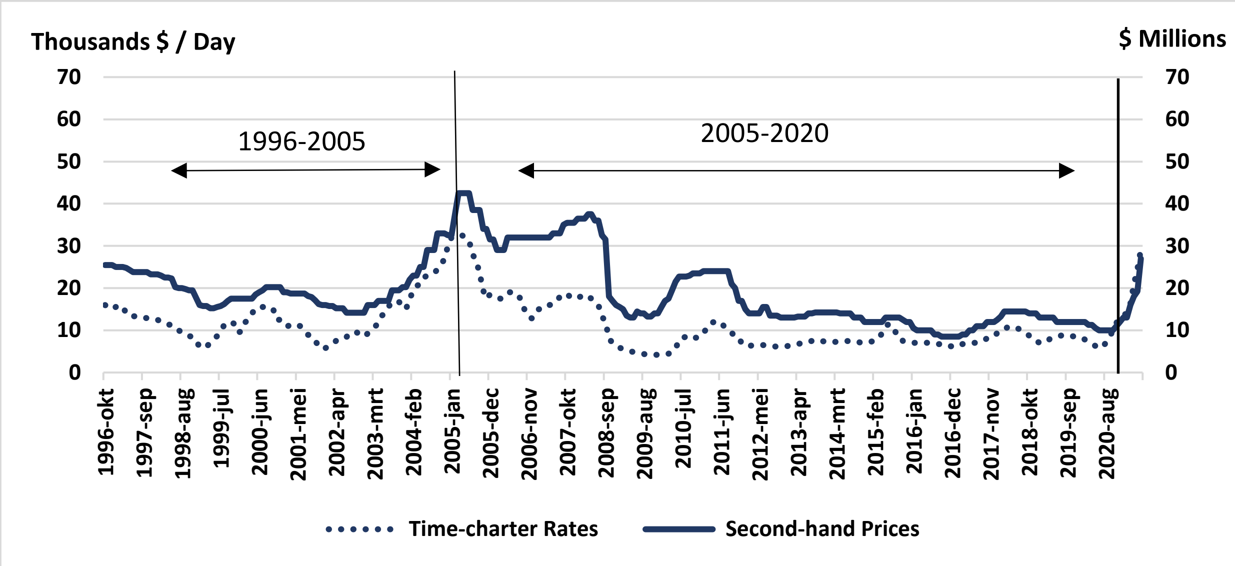
Figure 4.2: 725 TEU containership, time-charter earnings, and second-hand prices



Source: Own compilation based on Clarkson Research NV (2021)

Figure 4.3 describes the time-charter earnings and the second-hand prices for the 1,700 TEU container vessel for the period 1996-2021. Similarly, with the graph of the 725 TEU container vessels, two main periods can be distinguished. From 1996, there was a recovery in the market, with the time-charter earnings reaching their peak in 2005, while from that year till 2020, there was a market downturn. Moreover, both the prices and earnings present higher values, and they also fluctuate more than the 725 TEU containerships, while in the recovering years, the spread between those series was keen to narrow, and on the other hand, in the market's downturns, this spread keen to wide, which also indicates the relationship between those series. In 2020, the market began to recover, with earnings adapting faster than prices, reflecting the high volatility in this market.

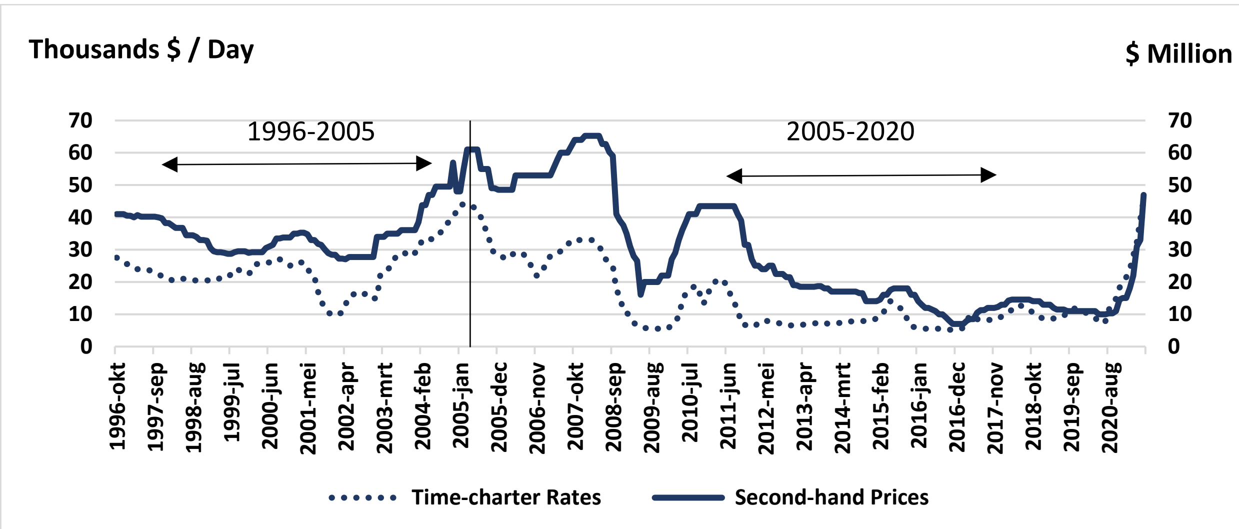
Figure 4.3: 1,700 TEU containership, time-charter earnings, and second-hand prices



Source: Own compilation based on Clarkson Research NV (2021)

In parallel, Figure 4.4 shows the second-hand prices and the time-charter earnings for the 3,500 TEU containerships. As indicated in the graph, under different market conditions, the series presents similar volatility and fluctuation to that of 1,700 TEU container vessels. However, in 2021, the market's upturn affected time-charter rates even more, indicating that, as vessel size increases, higher volatility exists in the market.

Figure 4.4: 3,500 TEU containership, time-charter earnings, and second-hand prices



Source: Own compilation based on Clarkson Research NV (2021)

In all three markets, 2005-2008 were the most productive period regarding the revenues. The second-hand prices also gained their highest values, indicating the imminent demand from the buyer's perspective. The high rates can be interpreted by the fact that in 2001, China entered the WTO and had been developing its economy by creating serious infrastructure, and therefore, enormous quantities of goods were transported by the shipping service. Between 2002 and 2007, China's steel production grew from 144 million tons a year to 468 million tons, adding capacity equivalent to that of Europe, Japan, and South Korea. Combined with the growth of oil imports and exports in 2003, this created a limited number of vessels. Tanker, container, and bulk carrier rates were driven to new highs, and despite some volatility, they stayed at these high levels for the following four years (Stopford 2009). Finally, due to disruption in the supply chain in all markets caused by COVID-19, in 2021, there was a spike in prices and earnings for all three second-hand container vessel sizes.

4.3.2 Statistical Analysis

The first step in the descriptive statistical analysis is to evaluate and compare the mean, median, and standard deviation of second-hand prices and operational earnings for the three vessel sizes. The results in Table 4-2 indicate that the mean levels of prices and the standard deviation for the 1,700 TEU and 3,500 TEU are higher than those of the 725 TEU containership. That means prices for larger vessels fluctuate more than prices for smaller ships. Jarque and Bera Test (1980) describes the normality test and is distributed in 2^{nd}-order as $x^2(2)$. Tests indicate significant departures from normality for time-charter earnings and second-hand prices in all vessels. Moreover, the autocorrelation test, proposed by Ljung and Box (1978), is performed using the Q statistics for 12th-order autocorrelations. Results from the test indicate that serial correlation is present in all price and profit series. Finally, the ARCH test, which is the Engle (1982) The test, for a 2nd-order (2 lags) ARCH effect, indicates the existence of autoregressive conditional heteroscedasticity in all series.

Table 4-2: Descriptive statistics of second-hand prices and time charter earnings for different-size container ships

	Containership 725 TEU 5yr old Second-hand Prices	**Containership 1700 TEU 5yr old Second-hand Prices**	**Containership 3500 TEU 5yr old Second-hand Prices**	**Feeder Containership 725 TEU 6-12 Month Timecharter Rate**	**Feeder Containership 1700 TEU 6-12 Month Timecharter Rate**	**Narrow Beam Containership 3500 TEU 6-12 Month Timecharter Rate**
	$ Million	$ Million	$ Million	$/Day	$/Day	$/Day
Mean	9.90	19.22	30.68	4,576.27	11,359.88	17,943.18
Median	9.45	16.25	29.25	4,000.00	9,400.00	16,500.00
Maximum	20.00	42.50	65.25	9,100.00	32,500.00	45,375.00
Minimum	4.50	8.50	7.00	3,200.00	4,200.00	5,150.00
Std. Dev.	4.17	8.10	15.61	1,246.90	5,883.37	10,247.11
Skewness	0.70	0.99	0.42	1.682	1.516	0.555
Kurtosis	2.50	3.07	2.23	5.623	5.305	2.363
JARQUE AND BERA-TEST						
Jarque-Bera	27.30	49.00	16.16	22.59	17.95	20.24
Probability	0.000001	0.000	0.00031	0.000	0.000	0.00004
ARCH-TEST						
Obs*R-squared	279.46	273.98	274.35	288.20	287.00	285.57
Prob. Chi-Square(2)	0.000	0.000	0.000	0.000	0.000	0.000
Q STATISTICS -TEST						
Q(12)	2,858.10	2,507.70	2,749.30	2,434.10	2,040.70	2,291.10
Prob	0.000	0.000	0.000	0.000	0.000	0.000

Source: Own compilation based on Clarkson Research NV (2021)

Table 4-3 describes the statistical analysis for logarithmic prices and logarithmic time charters for all types of vessels. Furthermore, Jarque and Bera Test (1980) indicates significant departures from normality for logarithmic time-charter earnings and second-hand prices in all vessels. The Ljung and Box (1978) Q statistics for 12th-order autocorrelations are all significant, indicating that serial correlation is present in all price and profit series. Finally, ARCH tests for 2nd-order (2 lags) ARCH effect indicate the existence of autoregressive conditional heteroscedasticity in all series.

Table 4-3: Descriptive statistics of logarithmic second-hand prices and logarithmic time charter earnings for different size container ships

	Containership 725 TEU 5yr old Second-hand Prices	**Containership 1,700 TEU 5yr old Second-hand Prices**	**Containership 3,500 TEU 5yr old Second-hand Prices**	**Feeder Containership 725 TEU 6-12 Month Timecharter Rate**	**Feeder Containership 1,700 TEU 6-12 Month Timecharter Rate**	**Narrow Beam Containership 3,500 TEU 6-12 Month Timecharter Rate**
	log return second-hand prices(%)	**log return second-hand prices(%)**	**log return second-hand prices(%)**	**log change time charter(%)**	**log change time charter(%)**	**log change time charter(%)**
JARQUE AND BERA-TEST						
Jarque-Bera	17.8940	13.4553	16.7601	71.3701	12.5450	22.9095
Probability	0.00013	0.001197	0.000229	0.0000	0.001888	0.000011
ARCH-TEST						
Obs*R-squared	281.75	278.12	281.00	288.49	285.80	276.99
Prob. Chi-Square(2)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Q STATISTICS -TEST						
Q(12)	3,002.90	2,556.30	2,846.70	2,451.90	1,955.00	2,251.00
Prob	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Source: Own compilation based on Clarkson Research NV (2021)

Augmented Dickey-Fuller tests (ADF) for the unit root test (Dickey and Fuller 1979) are performed on the log levels and log-differences of second-hand prices and time-charter rates for the three container ship sizes. Results from these tests indicate that log levels of all price and earnings series are non-stationary (Table 4-4) for all the level degrees (1%, 5%, and 10%) compared to the t-statistic result.

Table 4-4: Augmented Dickey-Fuller test statistics of logarithmic second-hand prices and logarithmic time charter earnings for different size container ships

	Hypothesized		Trace	0.05	Prob.**	Max-Eigen	0.05	Prob	Cointegrating Equation(s):
	No. of CE (s)	Eigenvalue	Statistic	Critical Value		Statistic	Critical Value		
container 725 TEU									**{1-θ1-θ0}**
LogTC and LogPrice	**None**	0.052936	20.5725	20.2618	0.0453	15.9360	15.8921	0.0492	1-0.126802
	At most 1	0.0157	4.6365	9.1646	0.3256	4.6365	9.1646	0.3256	-0.195565
container 1,700 TEU									**{1-θ1-θ0}**
LogTC and LogPrice	**None**	0.049975	20.7599	20.2618	0.0427	15.9725	15.8921	0.0669	1-0.060860
	At most 1	0.019159	5.6874	9.1645	0.2163	5.6874	9.1645	0.2163	-0.173255
container 3,500 TEU									**{1-θ1-θ0}**
LogTC and LogPrice	**None**	0.062881	24.2616	20.2618	0.0133	19.09389	15.8921	0.0152	1-0.191640
	At most 1	0.017424	5.1677	9.1645	0.2655	5.167736	9.164546	0.2655	-0.129776

Source: Own compilation based on Clarkson Research NV (2021)

On the contrary, the stationarity test is achieved in the first differences of the logarithmic series for second-hand prices and the time-charter earnings for all vessels, where the absolute t-statistic values are higher than those for 1%, 5%, and 10% significance. This result also indicates that the variables are integrated into order one (Table 4-5)

Table 4-5: Augmented Dickey-Fuller test statistics of the logarithmic first difference of second-hand prices and time charter earnings for different size container ships

Augmented Dickey-Fuller test statistic	Containership 725 TEU 5yr old Second-hand log(-1)-Prices	Containership 1,700 TEU 5yr old Second-hand log(-1)-Prices	Containership 3,500 t TEU 5yr old Second-hand log(-1)-Prices	Containership 725 TEU grd 6-12 Month log(-1)Timecharter Rate	Containership 1,700 TEU gls 6-12 Month log(-1)-Timecharter Rate	Containership 3,500 TEU gls 6-12 Month log(-1)-Timecharter Rate
t-Statistic	-7.7290	-5.2090	-4.5930	-5.9720	-8.4250	-9.2140
1% level	-3.4520	-3.4530	-3.4530	-3.4520	-3.4520	-3.4520
5% level	-2.8710	-2.8710	-2.8710	-2.8710	-2.8710	-2.8710
10% level	-2.5720	-2.5720	-2.5720	-2.5720	-2.5720	-2.5720

Source: Own compilation based on Clarkson Research NV (2021)

4.3.3 Cointegration and Causality

According to the econometric cointegration theory, two time series x_t and y_t are cointegrated if there is a parameter α such as:

$$u_t = y_t - \alpha x_t \qquad \textit{Eq. 4-1}$$

with α to be a stationary process. In other words, it can be considered that Y_t (y_{1t},...,y_{nt}) indicates an (n × 1) vector of I(1) time series. Y_t is cointegrated if there is an (n x 1) vectors $\beta=(\beta_1,....\beta_n)$ such as:

$$\beta' Y_t = 0\ Yt = \beta 1y1t + \cdots + \beta nynt \sim I(0). \qquad \textit{Eq. 4-2}$$

It is assumed that time series in Y_t are cointegrated if there is a linear combination that is stationary in I(0). According to the economic theory, this linear combination is referred to as a long-run equilibrium relationship, and the time series I(1) will be restored from any deviation from this equilibrium (Campbell and Perron, 1991).

To test the cointegration relationship for the time series of second-hand prices and time-charter earnings in the Dry Bulk shipping market, Alizadeh and Nomikos (2007) proposed the Johansen's (1988) reduced rank cointegration technique by estimating the vector correction model (VECM) as follows:

$$\Delta p_t = \sum_{\iota=1}^{q} \alpha\ \Delta p_{t-1} + \sum_{\iota=1}^{q} b\ \Delta \pi_{t-1} + \gamma_1(p_{t-1} - \theta \pi_{\tau-1} - \theta_0) + \varepsilon_{1,t}$$

$$\textit{Eq. 4-3}$$

$$\Delta \pi_t = \sum_{\iota=1}^{q} c\Delta p_{t-1} + \sum_{\iota=1}^{q} d\ \Delta \pi_{t-1} + \gamma_2(p_{t-1} - \theta \pi_{\tau-1} - \theta_0) + \varepsilon_{2,t}$$

The above vector equations (Eq. 4-3) were used as a cointegration relationship between the logarithmic earnings and logarithmic prices, and they were set up as a trading strategy, with the constant term in the error correction term θ_0, representing the long-run average term on the P/E ratio and the long-run equilibrium in the market. In their model, when the P/E ratio was greater than the long-run average term, ship prices were overvalued relative to earnings, or alternatively, the earnings were lower than the vessel prices. Therefore, when the P/E ratio was lower than the long-run average, it could be considered that the vessels were undervalued in terms of potential profits. As a result, in the following period, prices would likely increase to restore market equilibrium.

Finally, according to the Granger Representation Theorem, Granger (1969), if there is a cointegration between two time series, then at least one variable should Granger-cause the other. Alizadeh and Nomikos (2007) support that as ship prices are determined through the discounted present value of expected earnings, then the earnings should Granger-cause ship prices. Therefore, it can be considered that the (p/e) ratio contains information on future changes in ship prices, which can be used as an indicator for investment strategies.

Having identified that the time-charter earnings and second-hand vessel prices for the three container sizes are stationary in order one, or equivalent, in their first logarithmic differences, cointegration techniques are used next to examine the existence of a short-run and long-run relationship between these series.

The first step is to choose the number of lags in the Vector Error Correction Model (VECM). The lag length in the VECM model is chosen based on the indications of the following criteria:

1. Schwarz Bayesian Information Criterion (SBIC)
2. FPE: Final prediction error
3. AIC: Akaike information criterion
4. HQ: Hannan-Quinn information criterion

Second, the Søren Johansen (1988) reduced rank cointegration method is used to establish the cointegration relationship between ship prices and earnings, using the Trace and Max-Eigen t-statistics for the tests. Thirdly, having identified the existence of a cointegration relationship between second-hand prices and time-charter earnings for the three vessel sizes, a Vector Error Correction Model (VECM) is performed to test the causality between prices and earnings. More specifically, the lag length for the containerships of 725 TEU was selected by AIC and FPE criteria, with 4 lags (q=4), for containerships 1,700 TEU, and lags were 2 (eq=2) selected by all criteria. Finally, for container ships with a capacity of 3,500 TEU, the selected lags were 2 (eq=2), as selected by the AIC and FPE criteria.

Johansen's (1988) reduced rank cointegration method is then used to establish the cointegration relationship between ship prices and earnings. This method involves assessing the rank of the long-run coefficients matrix, C, through the Max-Eigen and Trace statistics, Johansen (1991). This method involves assessing the rank of the long-run coefficients matrix, C, through the Max-Eigen and Trace statistics. The rank of C, in turn, determines the number of cointegrating relationships; for instance, if rank(C) = 1, then there is a single cointegrating vector that describes the long-run equilibrium relationship between the variables. In this case, C can be factored as C = c H, where c and H are 2x1 vectors. Using this factor, the H represents the vector of cointegrating parameters, and c is the vector of error correction coefficients measuring the speed of convergence to the long-run steady state. The cointegration tests were performed with the assumption of no deterministic trend and with a restricted constant.

Table 4.6 describes the results of the test. The Max-Eigen and Trace statistics indicate the existence of one cointegrating vector between ship prices and time-charter for all vessels (acceptance of the null hypothesis {at most one cointegration} with probability higher than 5%, and rejection of the hypothesis of non-cointegration respectively). This means that log prices and log time-charter earnings are united through a unique long-run relationship. In this sense, any deviation from this equilibrium is reinstated through the short-term adaptation of these variables. In the same table, estimated cointegration vectors are also represented for the three ship sizes (1-θ1-θ0). These unrestricted cointegrating vectors are then used in the estimation of the VECM model.

Table 4-6: Result of Johansen's cointegration test of log- second-hand prices and log time-charter for different size container ships

	Hypothesized		Trace	0.05	Prob.**	Max-Eigen	0.05	Prob	Cointegrating Equation(s):
	No. of CE (s)	**Eigenvalue**	**Statistic**	**Critical Value**		**Statistic**	**Critical Value**		
container 725 TEU									**{1-θ1-θ0}**
LogTC and LogPrice	**None**	0.052936	20.5725	20.2618	0.0453	15.9360	15.8921	0.0492	1-0.126802
	At most 1	0.0157	4.6365	9.1646	0.3256	4.6365	9.1646	0.3256	-0.195565
container 1,700 TEU									**{1-θ1-θ0}**
LogTC and LogPrice	**None**	0.049975	20.7599	20.2618	0.0427	15.9725	15.8921	0.0669	1-0.060860
	At most 1	0.019159	5.6874	9.1645	0.2163	5.6874	9.1645	0.2163	-0.173255
container 3,500 TEU									**{1-θ1-θ0}**
LogTC and LogPrice	**None**	0.062881	24.2616	20.2618	0.0133	19.09389	15.8921	0.0152	1-0.191640
	At most 1	0.017424	5.1677	9.1645	0.2655	5.167736	9.164546	0.2655	-0.129776

Source: Own compilation based on Clarkson Research NV (2021)

In the cointegration vector model, residual diagnostics indicate that autocorrelation and heteroscedasticity are present in the residuals of all the regressions. Consequently, Newey and West (1987), correction for serial correlation and heteroscedasticity is applied to the standard errors of the regressions. Examination of the vector of error correction coefficients (Table 4-7) provides information for the equilibrium process for the three types of vessels.

For example, considering the 725 TEU container ships, the cointegrating vector is significant in both equations (Coint-Eqi=1,2). More specifically, consider the results for the D(LOGCP), which indicates the logarithmic first difference for second-hand prices, and the D(LOGTC), which is the logarithmic first difference for second-hand prices. T-statistics are (-0.008645) for the D(LOGCP) and (0.009687) for the D(LOGTC), indicating significance at 5% probability. Moreover, the signs of the speed of adjustment coefficient are compatible with the junction of TC earnings and ship prices to their long-run relationship (negative for ship prices and positive for TC earnings). For example, in response to a positive deviation from their long-run relationship at period t-1, i.e. pt-

1-θ1pt-1-θo > 0, ship earnings in the next period will increase, and ship prices will decrease, resulting in the equilibrium achievement in the market.

The same statistical results are achieved by the other two container ship sizes. In both markets, the cointegrating vector is significant in both equations (Coint-Eqi=1,2), and the signs of the speed of adjustment coefficients are compatible with the junction of TC earnings and ship prices in their long-run relationship. Finally, R-squared values indicate the significance in the VECM models, while the coefficients for the time-charter rates (D(LOGTC)) present better fits, and therefore, they can interpret the model more accurately.

Table 4-7: Result of VECM for 725, 1,700 and 3,500 container vessels

	Container 725 TEU		**Container 1700 TEU**		**Container 3500 TEU**	
D(LOGCP)	**D(LOGCP)**	**D(LOGTC)**	**D(LOGCP)**	**D(LOGTC)**	**D(LOGCP)**	**D(LOGTC)**
Coint-Eqi=1,2	-0.0086	0.0097	-0.0151	0.0203	-0.0202	0.0212
	-0.0050	-0.0031	-0.0077	-0.0089	-0.0071	-0.0088
Speed of adjustment	[-1.72003]	[3.17175]	[-1.96646]	[2.27111]	[-2.83871]	[2.41511]
D(LOGCP(-1))	0.0942	0.1268	0.0315	0.0609	0.0130	0.1916
	-0.0610	-0.0371	-0.0651	-0.0757	-0.0604	-0.0744
Speed of adjustment	[1.54386]	[3.42155]	[0.48371]	[0.80411]	[0.21502]	[2.57583]
D(LOGTC(-1))	0.1956	0.2384	0.1733	0.5363	0.1298	0.4723
	-0.0969	-0.0589	-0.0545	-0.0633	-0.0490	-0.0603
Speed of adjustment	[2.01911]	[4.05095]	[3.17875]	[8.46603]	[2.65089]	[7.82916]
R-squared	0.192943	0.357671	0.211101	0.375635	0.225414	0.327932

Source: Own compilation based on Clarkson Research NV (2021)

Table 4-8 presents the statistical analysis for the causality test between the prices and the earnings for the three vessel sizes. The test that was performed was the Wald test. According to the Granger (1986) representation theorem, if two time series are cointegrated, then causality must exist in at least one direction. In theory, it is expected that earnings to Granger cause ship prices. After imposing the appropriate restrictions on the VECM model, the results for these variables were examined. The test is conducted to examine the long-run and short-run relationships between prices and earnings. It can be considered that there is a long-run causality from earnings to prices (DCT -> DCP/prob.<0.05 or 5%) for all the vessels, and there is causality from prices to earnings (DCP -> DCT/prob.<0.05 or 5%) for the bigger vessels. Finally, there is a short-run causality from earnings to prices (DCT -> DCP) for all the vessels.

Table 4-8: Statistical analysis for the causality test between second-hand prices and time-charter earnings

	Container 725 TEU			**Container 1,700 TEU**			**Container 3,500 TEU**		
short run causality	**Value**	**df**	**Prob.**	**Value**	**Df**	**Prob.**	**Value**	**df**	**Prob.**
DCP->DTC	30.895	4	0	147.052	2	0.4794	87.572	2	0.0125
DCT->DCP	16.793	4	0.0021	225.427	2	0	21.785	2	0
long run causality	**Coefficient**	**t-Statistic**	**Prob.**	**Coefficient**	**t-Statistic**	**Prob.**	**Coefficient**	**t-Statistic**	**Prob.**
DCP->DTC	-0.0086	-1.720	0.086	-0.0151	-1.966	0.0497	-0.0317	-2.415	0.016
DTC->DCP	-0.0334	-3.172	0.0016	-0.0300	-2.271	0.0235	-0.0202	-2.839	0.0047

Source: Own compilation based on Clarkson Research NV (2021)

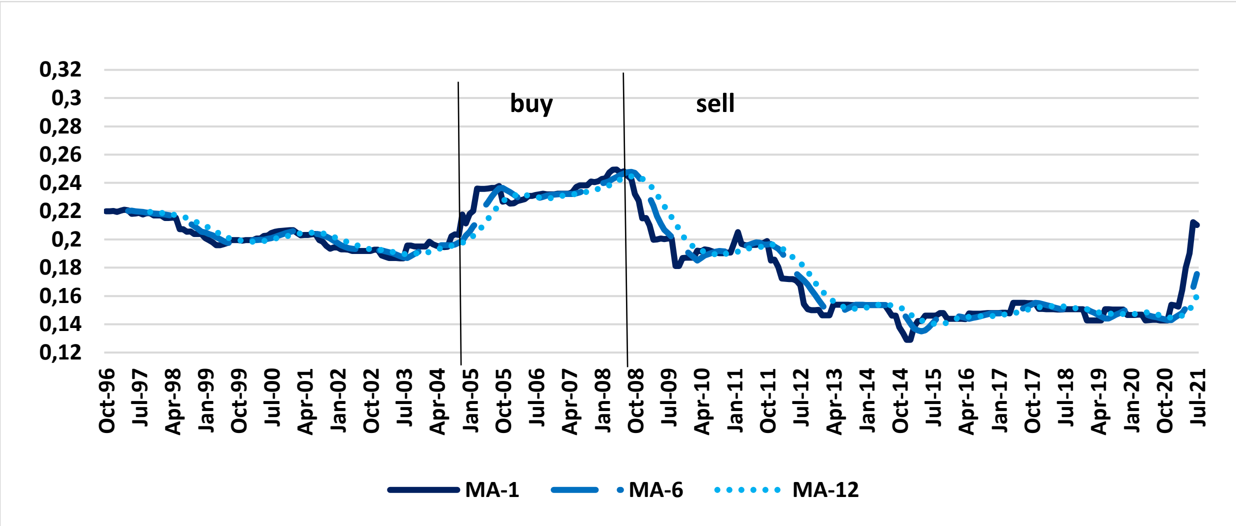
4.3.4 Trading Rules and Profitability

In order to set up trading strategies, two simple moving average-based rules were applied to exemplify the importance of the price-earnings relationship in determining ship prices, and therefore market timing in the sale and purchase market for container ships. The strategy is based on two moving averages, one fast, such as MA-1, and two slower ones, MA-6 and MA-12, illustrating the monthly average returns. The difference between the two constructed MA series is then used as an indicator for buy and sell timing decisions in the market.

A positive difference between the slow and the fast MA series signals a sell decision, while a negative difference signals a buy decision. For example, in the container market for vessels 725

TEU (Figure 4.5), from October-1996 till October 1999, the slower moving averages (MA-12, MA-6) were higher than the faster one (MA-1), illustrating a sell timing decision, as well as in the years 2008-2010 and 2011-2013. On the contrary, from June 2003 to October 2005, the faster-moving average was higher than the slower ones, indicating a buy decision.

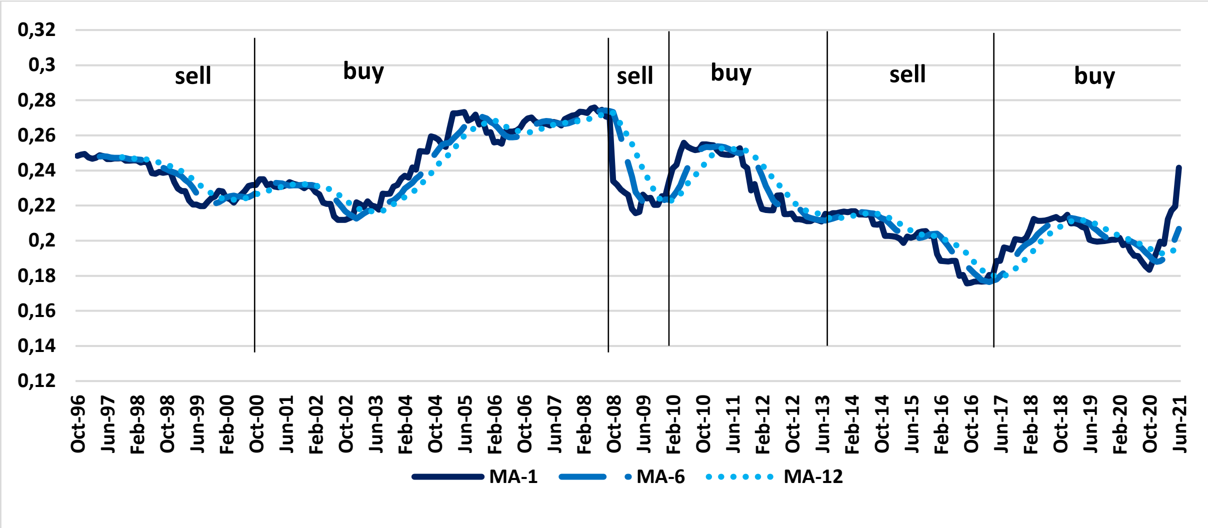
Figure 4.5: Plot of moving average MA-12, MA-6, and moving average MA-1 of the historical log-price–earnings ratio in 725 TEU second-hand container mark



Source: Own compilation based on Clarkson Research NV (2021)

Figure 4.6 and Figure 4.7 show the moving average strategies for the 1,700 TEU and 3,500 TEU container vessels. An interesting examination of the results is the similar patterns for the moving averages followed by all the container ship markets in the years under different economic conditions. For example, in the years of the economic crisis in 2008-2010, and the years 2011-2013 in all markets, the slower moving averages (MA-12, MA-6) were higher than the faster one (MA-1), illustrating a sell decision, while in years January-2003 till December 2008 the faster-moving average was higher than the slower ones, showing a buy decision.

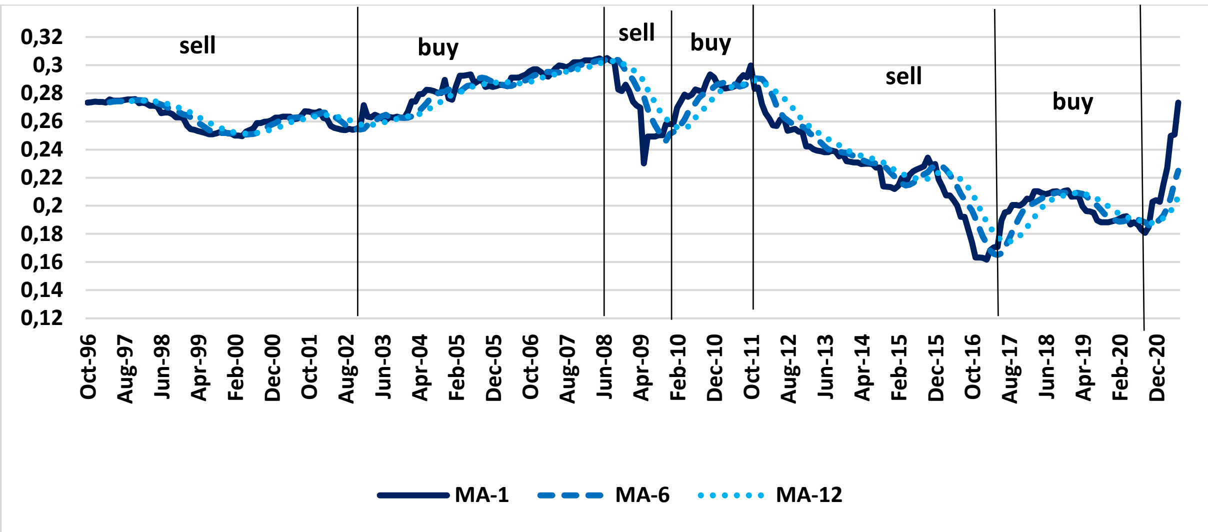
Figure 4.6: Plot of moving average MA-12, MA-6 and moving average MA-1 of historical log-price–earnings ratio in 1,700 TEU second-hand container market



Source: Own compilation based on Clarkson Research NV (2021)

The economic crisis of 2008 was determined as one of the most intense downturns for the shipping sector, especially for the containership market. During that time, as the world demand decreased significantly, the freight rates fell to nearly all-time lows. This impact was more pronounced during the period of the financial boom (2002-2007), when shipowners were driven to aggressively expand their fleets. Moreover, as the sector was considered profitable, many companies invested in new and bigger vessels. By the time of the vessel's delivery, the supply had exceeded the demand, driving the market to overcapacity. Furthermore, in 2012, the reduction in demand in Europe obliged the container liner operators to stop their contracts, as they could not pay for their chartered ships. Moreover, many small owners who could not afford their depths were forced out of the industry. This also led many banks to bankruptcy. Finally, due to low cargo demand, reduced freight rates, and lower vessel speeds, the time-charter rates dropped drastically. This decline was faster and more notable, as exogenous market characteristics, such as negative economic expectations, created adverse effects for market players (Kalgora and Christian 2016).

Figure 4.7: Plot of moving average MA-12, MA-6, and moving average MA-1 of historical log-price–earnings ratio in 3,500 TEU second-hand container market



Source: Own compilation based on Clarkson Research NV (2021)

Evaluating the performance of moving average strategies, the average returns (mean returns from log-p/e) were calculated for each strategy: MA-1, MA-6, and MA-12. Moreover, one alternative way was considered to calculate the decision of the Buy and Hold strategy. For this purpose, it was assumed that the ship was purchased from its company from the beginning of the research (October 1996) and remained in its possession throughout the entire analysis period. It was also agreed that the vessel depreciates and loses value due to wear and tear each month. This is estimated as the average decline in the value between a 5-year-old and a 10-year-old vessel and is 0.2% per month for 725 TEU container vessels, 0.6% and 0.8% for 1,700 TEU and 3,500 TEU, correspondingly. Finally, operating profits are calculated for the entire month, estimated on the assumption that the vessel will be on hire for 29 days per month or 348 days per year. The remaining 17 days per year represent time off-hire for repairs and maintenance. The projected strategy is structured and performed in an entirely forward-looking way. In other words, investment decisions at any point in time are made based on the information available to investors at that specific point in time. This way, a more realistic and precise representation is provided concerning the performance of the trading strategies.

Table 4-9 presents the mean returns, the standard deviations of returns, and the Sharpe ratios, which scale the mean returns by their standard deviations. It can be distinguished that both the

(MA-6) and (MA-12) strategies outperform the buy-and-hold strategy, as indicated by the Sharpe ratios across 1,700 TEU and 3,500 TEU container markets. For instance, when the MA-12 trading rule is applied, the Sharpe ratios for the 1,700 TEU and 3,500 TEU containers, which are enlarged to 9,4183 and 7,2073, respectively, reflect the joint effect of an increase in mean returns and a decrease in standard deviations of returns in each market. It can also be observed that the gain from such investment strategies and trading rules is greater in markets for larger vessels, due to higher volatility in these markets and better or more frequent trading opportunities arising from such price variations. On the other hand, for the 725 TEU second-hand container market, the buy-and-hold strategy outperforms trading strategies, as indicated by the mean returns and Sharpe ratios.

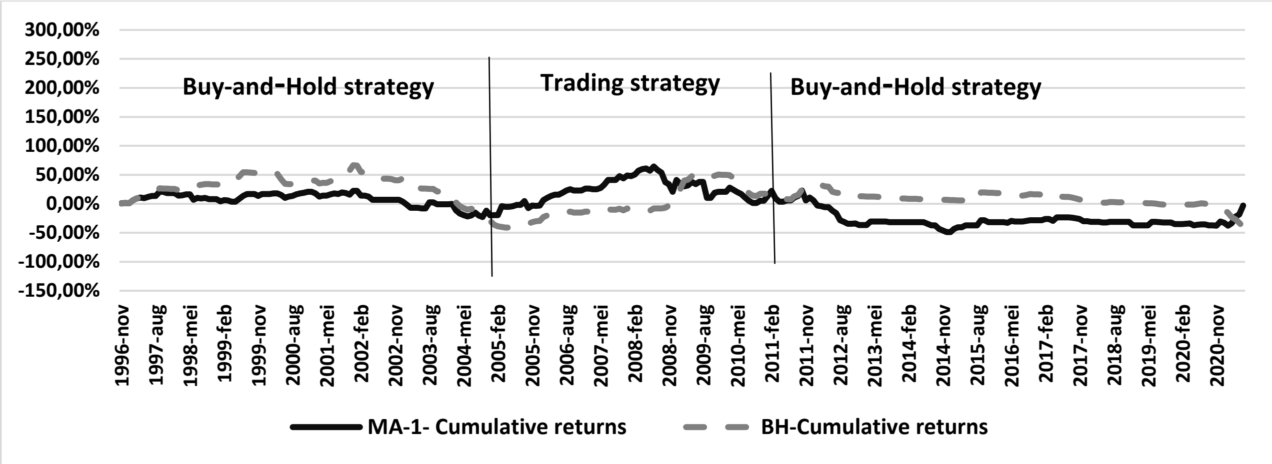
Table 4-9: Statistical results of trading strategies for different second-hand container vessel sizes

	MA-6			**MA-12**			**BUY AND HOLD**		
	725 TEU	**1,700 TEU**	**3,500 TEU**	**725 TEU**	**1,700 TEU**	**3,500 TEU**	**725 TEU**	**1,700 TEU**	**3,500 TEU**
MEAN RETURNS	0.187	0.228	0.251	0.187	0.228	0.251	0.202	0.188	0.193
STD	0.030	0.025	0.035	0.032	0.024	0.035	0.013	0.039	0.048
SHARPE RATIO	6.189	9.181	7.086	5.866	9.418	7.207	15.014	4.793	4.030

Source: Own compilation based on Clarkson Research NV (2021)

The cumulative returns on the ‘‘buy and hold’’ and the (MA-12) trading rule investment strategy for the 725 TEU vessel are shown in Figure 4.8. It can be observed that, while the "buy and hold" strategy outperforms the trading strategy for almost the whole period of the analysis, in profitable markets such as 2004-2008, the trading strategy yields higher profits for the owners due to higher earnings compared to the stock prices.

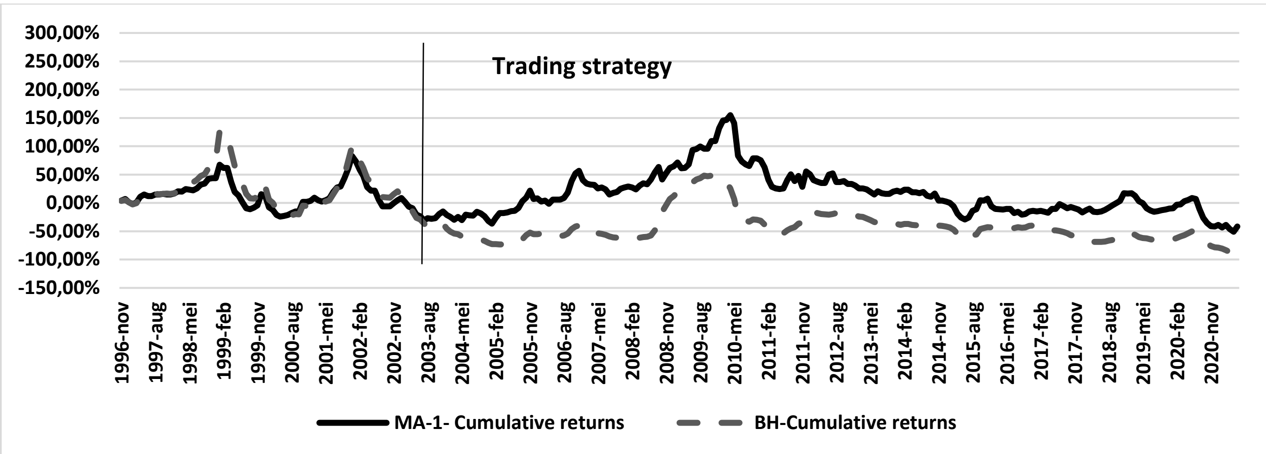
Figure 4.8: Cumulative returns on Buy and *Hold and MA trading strategy for 725 TEU second-hand container ships*



Source: Own compilation based on Clarkson Research NV (2021)

Figure 4.9 represents the cumulative returns for the 1,700 TEU containerships. Compared to the 725 TEU container vessels, when the trading rule (MA-1) is used, the significance of cumulative returns increases compared to the "buy and hold" strategy. This evidence is clear from 2003 when the economic boom affected the containership market, and many owners and investors ordered new vessels. Moreover, it can be noticed that, due to higher market volatility, even during the period of the economic crisis, many investors could yield higher profits from trading strategies than the buy-and-hold decision.

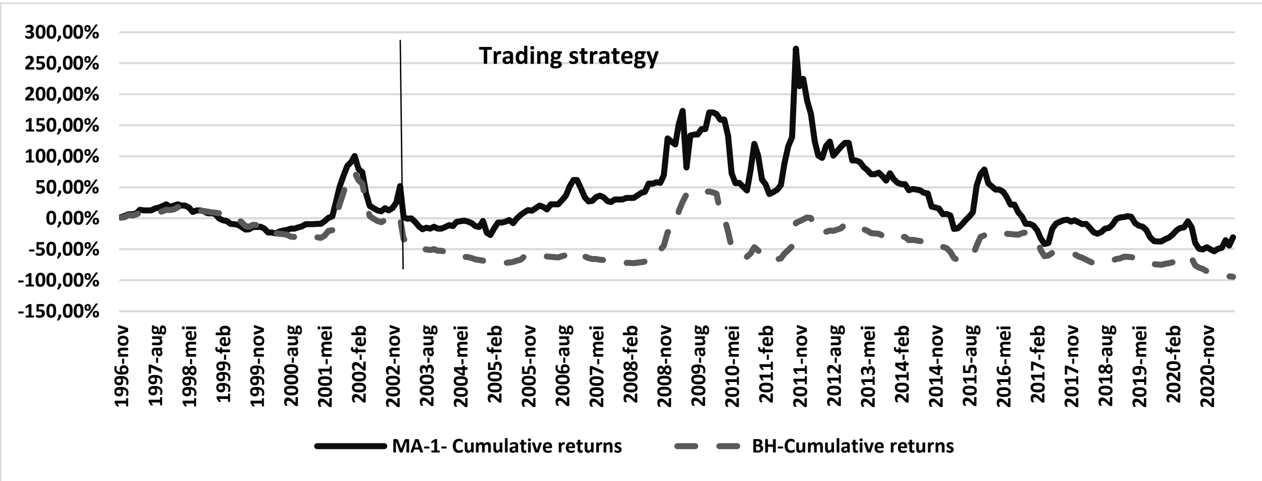
Figure 4.9: Cumulative returns on Buy and *Hold and MA trading strategy for 1,700 TEU second-hand container ships*



Source: Own compilation based on Clarkson Research NV (2021)

Between the prices and the earnings, the high volatility is even more perceivable in the containers of 3,500 TEUs (Figure 4.10). Similar to the 1,700 TEUs vessels, the trading decisions outperform the buy-and-hold strategy, and this comparison is more evident under the different market conditions, for example, in 2003-2008 and 2011-2015. In all three container shipping markets, it can be noticed that market booms (for example, 2005-2008) provide valuable opportunities for the "asset play" through trading strategies, while this observation is more evident for the larger vessels due to higher price volatilities.

Figure 4.10: Cumulative returns on Buy and *Hold and MA trading strategy for 3,500 TEU second-hand container*



Source: Own compilation based on Clarkson Research NV (2021)

4.3.5 Bootstrapping Re-Sampling

In the previous section, essential results were gained for the proposal of the trading strategies. However, a critical issue that supervenes when evaluating technical trading rules is that of data snooping. According to Sullivan et al. (1999) and White (2000), data snooping occurs when a dataset is used more than once for data selection and inference purposes. In other words, using the same set of data often to test strategic transactions may increase the likelihood of satisfactory results due solely to chance or the use of backward information rather than the superior ability of trading strategies.

The most commonly used method in the literature for evaluating the performance of trading strategies and testing for snooping data is the bootstrap, which was also suggested by Alizadeh and Nomikos (2007) for the dry bulk shipping market. The bootstrap, introduced by Efron (1979), is a re-sampling method that uses the empirical distribution of the statistic of interest rather than the theoretical distribution to conduct statistical inference.

The basic idea of bootstrapping is that the inclusion of a population from sample data can be modelled by resampling the sampling data and drawing conclusions about a sample of data that has been resampled. More typically, the bootstrap works by addressing the inclusion of the true probability distribution J, given the original data, as a function of extracting its empirical distribution, considering the sampling data. The accuracy of the conclusions regarding the use of the data that has been sampled can be appreciated because, as it is known, if ∪ is a logical approach to J, then the quality of the conclusion for J can, in turn, be deduced.

However, the ordinary bootstrap method is only valid in the case of independent and identically distributed (iid) observations. When ordinary bootstrap techniques are applied to serially dependent observations, as is the case with ship prices and earnings, the resampled series will not retain the original dataset's statistical properties, yielding inconsistent results and statistical inference. One method to overcome this phenomenon was introduced by Politis and Romano (1994). The method presented was the stationary bootstrap. This procedure is based on resampling blocks of random length, where the length of each block follows a geometric distribution, Sullivan et al. (1999). Therefore, to make a statistical estimation of the performance of strategic trading, the stationary bootstrap technique is used to generate random paths that may be followed by ship prices and profits during the sampling period while maintaining the distributive properties of the initial series.

More specifically, the logarithmic prices and time-charter, a random path for each sample, and a matrix of (297{number of original samples} *1000 {number of bootstraps} were recreated. Then, the moving average techniques were performed in each sample, and the means were obtained, as mentioned in the previous section. Table 4-10 presents the mean returns, the standard deviations of returns, and the Sharpe ratios, which scale the mean returns by their standard deviations. The results are similar to the outcomes of the actual series data in the preview analysis. For instance, when the (MA-6) trading rule is applied, the Sharpe ratios for containers 1,700 TEU and 3,500 TEU, increased to 9,19665 and 7,098149 respectively, reflecting the joint effect of increase in mean returns and decreased in standard deviations of return in these vessels, though for 725 TEU containers the mean returns are higher when the buy and hold strategy is applied.

Table 4-10: Result of bootstrap simulation of trading strategies for second-hand container vessels

	MA-6			MA-12			BUY AND HOLD		
	725 TEU	1,700 TEU	3,500 TEU	725 TEU	1,700 TEU	3,500 TEU	725 TEU	1,700 TEU	3,500 TEU
MEAN RETURNS	0.187	0.228	0.251	0.187	0.228	0.251	0.202	0.187	0.193
STD	0.032	0.025	0.035	0.032	0.024	0.035	0.013	0.039	0.048
SHARP RATIO	5.824	9.197	7.098	5.876	9.435	7.220	15.055	4.808	4.043

Source: Own compilation based on Clarkson Research NV (2021)

The statistical analysis of the bootstrap techniques for each type of vessel, all the moving average bootstrapped techniques, and the buy and hold strategy are represented in Table 4-11. The empirical confidence intervals are constructed at a 95% confidence level to test whether the p/e-based trading strategies provide significantly higher returns than the holding strategy. These are constructed as 2.5% and 97.5% percentiles. If the value of the t-statistic is not defined between the confidence interval, then the simulations on the “Moving average” and the “buy and hold” strategies are not significant at the 5% level. The results indicate that both simulation strategies (MA and buy-and-hold strategy) are significant. Therefore, the results from the previous section about the strategic decisions can be accepted.

Table 4-11: Statistical results and interval coefficients of the bootstrap simulation

Container 725 TEU	MA-1	MA-6	MA-12	BUY AND HOLD
Parameters	Estimator (Bootstrap)	Estimator (Bootstrap)	Estimator (Bootstrap)	Estimator (Bootstrap)
Mean	0.186912	0.18664	0.186597	0.201742
Median	0.1930	0.192681	0.192924	0.19996
2,5-Percentile/Lower bound (B.C. percentile interval)	0.1428	0.142946	0.142148	0.17984
97,5-Percentile/Upper bound (B.C. percentile interval)	0.2428	0.242309	0.240952	0.222451
Resampled statistics	0.2199			0.21971
Container 1,700 TEU	MA-1	MA-6	MA-12	BUY AND HOLD
Parameters	Estimator (Bootstrap)	Estimator (Bootstrap)	Estimator (Bootstrap)	Estimator (Bootstrap)
Mean	0.22773	0.2277	0.227828	0.187488
Median	0.225504	0.224762	0.226403	0.18967
2,5-Percentile/Lower bound (B.C. percentile interval)	0.180234	0.181548	0.182394	0.120101
97.5-Percentile/Upper bound (B.C. percentile interval)	0.272798	0.271572	0.269513	0.250021
Resampled statistics	0.248219			0.249707
Container 3,500 TEU	MA-1	MA-6	MA-12	BUY AND HOLD
Parameters	Estimator (Bootstrap)	Estimator (Bootstrap)	Estimator (Bootstrap)	Estimator (Bootstrap)
Mean	0.251205	0.251128	0.25137	0.193111
Median	0.259844	0.260116	0.26021	0.19387
2,5-Percentile/Lower bound (B.C. percentile interval)	0.17669	0.179032	0.181189	0.10651
97,5-Percentile/Upper bound (B.C. percentile interval)	0.302597	0.301863	0.300384	0.271038
Re-sampled statistics	0.3025966			0.273273

Source: Own compilation based on Clarkson Research NV (2021)

4.4 Discussion and Conclusions

Investment and trading strategies have significant implications for maritime investors due to market complexities and the intense volatility dynamics in the market. Moreover, new regulations imposed by the IMO towards decarbonisation and the energy transition for green operations insert even more restrictions on maritime investments and the owner's operational decisions. In the maritime sector, empirical research has been focused on pricing models and freight revenue drivers, while much emphasis has been given to the scale increase in vessel sizes, the excess capacity, and the cost reduction through economies of scale. Several studies (Alizadeh and Nomikos, 2006; Alizadeh and Nomikos, 2007) examined the profitability in the sales and purchase market for the Tanker and the Dry Bulk sector, and it was suggested that there are profitable opportunities for second-hand vessels through the trading strategies. However, in the containership market, research concerning second-hand vessels is very scarce, while much emphasis has been given to the very large containerships, rather than the smaller vessels.

This paper differentiates from the previous literature and provides a novel insight into the container sector for three main reasons. Firstly, it concerns the investment processes, where the literature is already very limited. Secondly, compared to other research, this paper focuses only on the small second-hand container vessels and their profitable opportunities through the "asset play". As indicated, despite the oligopoly characteristics of the container sector, under different market conditions, the second-hand market is driven mainly by the freight rates, future expectations, and the vessel's age, and it can provide profitable opportunities to investors. In addition, the main reason that only small ships were included in the scope of the analysis is that larger container ships were brought onto the market after the economic boom (2005-2008), and there is not yet a second-hand market for the very large ships (> 17,000 TEUs). Thirdly, the period of the analysis in this paper (1996-2021) covers two critical timing periods for the maritime sector, namely the economic boom (2004 – 2007) and the economic crisis of 2008-2012. Therefore, this research also contributes to a complete understanding of the second-hand containership industry and its development through that period.

To evaluate the profitable opportunities in the sales and purchase market for second-hand container vessels, this research used a similar methodology developed by Alizadeh and Nomikos

(2007). More specifically, this paper examined the historical data of the second-hand prices and the monthly time-charter rates from October 1996 to June 2021 for the three containerships distinguished by their sizes: 725 TEUs, 1,700 TEUs, and 3,500 TEUs. In addition, using the cointegration technique, the long-run relationship and short-run causality between the second-hand prices and the time-charter earnings were examined. This relationship was used as an indicator for the investment or divestment decisions, applying the Moving Average technique. Finally, the bootstrap resampling test was used to re-evaluate the results from the original time series.

Statistical results point out that second-hand prices for 3,500 TEU container vessels fluctuate more than prices for 725 TEU and 1,700 TEU containerships. In addition, cointegration tests indicated the relationship between the time-charter earnings and the second-hand prices, which can be used as an indicator of future price movements, and therefore as an index for the timing of the investments. The results of the Moving Average technique, as well as the annual cumulative returns, showed that the sale and purchase strategy yields higher profits than the buy-and-hold strategy for the 1,700 TEU and the 3,500 TEU container vessels, reflecting the joint effect of an increase in mean returns and a decrease in standard deviations of return in each market. It was also noticed that in the market upturns, for example, the years 2004-2008, the decision to purchase a vessel was considered more profitable, while in the market downturns (2008-2010), the selling decisions could yield higher profits. It was indicated that the gain through such investment strategies was greater in the markets for larger vessels due to higher volatility, and better or more frequent trading opportunities could arise due to such variation in prices. On the other hand, for the 725 TEU second-hand container market, the buy-and-hold strategy outperformed the trading strategy. However, during the economic boom, when the market was considered more profitable, trading decisions could yield higher profits than the passive buy-and-hold strategy. The bootstrap resampling technique indicated similar results for all three container vessel sizes. Generally, it is suggested that the market for smaller vessels is more efficient as there are more shipowners, and these vessels are more flexible in their operations. From the same perspective, larger ships could be more suitable for asset play, but the timing of the investments is crucial as the gains or losses are more imminent in these sectors (Alizadeh and Nomikos, 2007).

What can shipping market operators and investors learn from this empirical analysis? First, they can find profitable opportunities, including sales and purchases of vessel operations. As it was suggested in this research, the potential profits from the trading strategies in the second-hand container market are highly correlated with the large vessels of 1,700 TEU and 3,500 TEU due to the higher volatility in those markets. On the other hand, for smaller ships such as 725 TEU containerships, the buy-and-hold decision outperforms the trading strategy. Therefore, for investors operating with very small container vessels, the decision to keep the vessel is considered more profitable. However, this strategy was not evident during the market upturns, as the trading strategy outperformed the Buy-and-hold decision. Secondly, a critical application in the decision-making concerns the timing of the investments. As indicated, under different market conditions (market booms or market downturns), decision-making has different effects (whether an investor has to buy or sell a vessel). This analysis showed that in market upturns, investors could achieve profits by purchasing a vessel and selling it when the market conditions declined. This observation was more evident for bigger vessels (1,700 TEUs and 3,500 TEUs) due to higher price volatilities.

From the academic perspective, it is indicated that the price-to-earnings (p/e) ratio contains essential information regarding investment timing and trading strategies in the shipping market, while using the cointegration relationship, a strategy that measures the deviation of the p/e ratio from its long-run equilibrium may give signals for sale and purchase opportunities. However, as this paper concerns only three container vessel sizes (viz. 725 TEUs, 1,700 TEUs, and 3,500 TEUs), a future analysis could be applied to bigger container ships. Moreover, as time-charter rates were used as revenue, future research can consider the spot rates. In addition, a similar methodology can be applied to other types of vessels (for example, the Ro-Ros or LNGs), while it can also be implemented in other transportation modes, such as railways and the aviation industry. Finally, future research can be focused more extensively on the p/e relationship and the way that those variables can be interpreted. Overall, this research can provide valuable information for investors' profitable opportunities and future strategies.

Chapter 5: Essay 4 - Price Premiums for Alternative-Fuel Containerships in the New Building Market

Investment decisions in new-building vessels are increasingly influenced by the adoption of alternative fuels and emission-reduction technologies, yet their cost implications remain insufficiently explored. This study scrutinises 1,708 new-building contracts from January 2010 to October 2024, using panel data econometric techniques to assess the cost premium for greening on containership new-building prices. Results show that vessels with alternative fuels (LNG, hybrid, methanol) are associated with substantial price premiums of 29.05% for LNG, 23.37% for hybrid, and 18.29% for methanol compared to conventional VLSFO-fueled containerships. In addition, scrubber-equipped vessels show a smaller cost premium (~5.55%). Moreover, regional price differences reveal China's 9.34% cost advantage over the Republic of Korea, and Japan, while there is no significant price gap between Japan and the Republic of Korea. Findings suggest that green technology valuation is driven more by compliance costs and vessel characteristics than by the shipyard's specifications. This essay is crucial for policymakers, shipyards, shipowners, and energy suppliers, as it provides deeper insights into regulatory compliance and the evolving dynamics of the new building market.

5.1 Introduction

In the maritime sector, broader industry challenges persist, including ongoing global supply chain disruptions post-COVID-19 (i.e., port congestions, equipment shortages, etc.), increasing geopolitical tensions, and stringent environmental regulations aimed at decarbonisation. Notably, the maritime sector is a major contributor to greenhouse gas (GHG) emissions, accounting for approximately 2.1% of global emissions, with container liner shipping exhibiting higher per ton-mile carbon intensity compared to dry and liquid bulk shipping (UNCTAD, 2024).

As was discussed in the Essay 2.4.1, in response to the climate impact, the IMO set initial reduction targets in 2018, aiming for a 50% cut in GHG emissions by 2050 compared to 2008 levels, while in July 2023, these targets were revised to include a 40% reduction in carbon intensity by 2030, a 5–10% adoption of low-emission technologies by 2030, and full emissions neutrality by 2050 (IMO, 2023). A key measure introduced by the IMO is the EEDI, formally adopted during the 62nd session of the *Marine Environment Protection Committee (MEPC 62)* through amendments to MARPOL Annex VI, phased in since 2013, requiring efficiency improvements of 10% (Phase 1), 20% (Phase 2), and up to 30% from 2025 (Phase 3). In 2023, the EEXI and CII came into force, rating ships A (most efficient) to E (least efficient). A ship rated D for three consecutive years or E once must update its Ship Energy Efficiency Management Plan (SEEMP) with a corrective action plan (IMO, 2022).

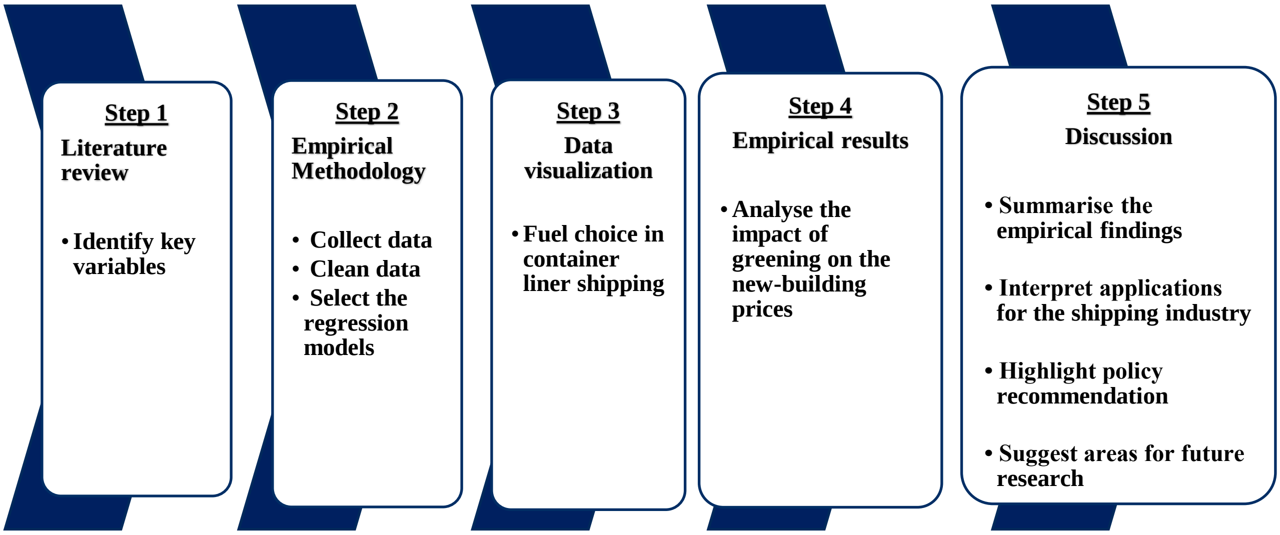
Similarly, under the European Commission's "Fit for 55" legislative package, introduced in 2021, ships must reduce emissions by 55% relative to 1990 levels by 2030 and achieve climate neutrality by 2050 (European Commission, 2021). Maritime transport entered the EU Emissions Trading System in 2024, covering 40% of emissions, rising to 100% by 2026. Furthermore, EU allowance prices are expected to climb from €76.9/tCO_2 in 2025 to €92.5/tCO_2 in 2026 (Reuters, 2024), raising costs for conventional vessels, while from 2025, the FuelEU Maritime regulation will require a 2% cut in fuel GHG intensity, rising to 80% by 2050 (European Commission, 2023). Moreover, the Carbon Border Adjustment Mechanism (CBAM), starting in 2026, will add carbon costs on imported shipbuilding materials like steel (European Commission, 2025), increasing the cost for fossil-fuel vessels and incentivising investment in low-carbon designs.

Traditionally, key drivers influencing shipowners' investment decisions in the newbuilding market included freight market conditions, second-hand vessel prices, and overall market sentiment, with China, the Republic of Korea, and Japan leading global production (Stopford, 2009). Historically, investment decisions, as reflected in newbuilding contracts, have closely followed market conditions, including trade volume, newbuilding prices, and secondhand vessel prices. Notable peaks in the order book have occurred during periods of strong market conditions, such as in 2005 (605 contracts) and 2007 (578 contracts). Conversely, during economic downturns or periods of weak market sentiment, such as the economic and financial crisis in 2009, new vessel orders sharply declined due to reduced demand and excess ship supply. After 2013, however, regulatory pressures began to exert a stronger influence on investment decisions, introducing new uncertainties regarding future vessel requirements. The implementation of the Energy EEDI by the IMO, followed by stricter regulations such as the IMO 2020 sulfur cap and the FuelEU Maritime initiative, into force in January 2025, and other incentives (e.g., CII, ballast water treatments, etc.) forced shipowners to account for compliance costs, making them more cautious about new investments. These regulations required more fuel-efficient and environmentally compliant vessels, increasing upfront costs and raising concerns about the long-term viability of older technologies. As a result, shipowners delayed orders, leading to greater volatility in new-building activity between 2016 and 2021, with orders fluctuating between a low of 129 contracts in 2016 and a sharp rebound to 638 contracts in 2021 during the post-pandemic market recovery, highlighting the investment behavior driven by increased liquidity and capital availability, regulatory compliance (e.g., Fit for 55, FuelEU Maritime and ETS inclusion), and advancements in fuel technologies (Clarksons Research NV, 2025).

Over the last decade, the shipping industry has been adopting advanced technologies such as exhaust gas cleaning systems (scrubbers) to reduce sulfur oxides and eco-vessel designs to improve energy efficiency, to meet the IMO and EU regulatory and environmental challenges. To this extent, alternative fuels, including liquefied natural gas (LNG), methanol, ammonia, hydrogen, and other synthetic fuels, offer promising pathways toward decarbonisation (Balcombe et al., 2019; Lee and Nam, 2017a; Wan et al., 2018; Al-Enazi et al., 2021; Foretich et al., 2021). In addition, as ship construction accounts for approximately 5–9% of the total lifecycle CO_2 emissions, largely due to the carbon-intensive production of steel and energy-demanding manufacturing processes (OECD, 2025), policies such as China's "Double Carbon" strategy aim to peak carbon emissions by 2030 and achieve carbon neutrality by 2060, presenting significant implications for the shipbuilding industry, promoting investments in low-carbon production methods and the development of alternative-fuel vessel designs. Recent studies have also highlighted the role of renewable energy, digitalisation, and modular design in shipbuilding (Vakili et al., 2023; McKenney, 2024), suggesting that ships increasingly require advanced technologies, including dual-fuel engines, specialised fuel tanks, and enhanced safety systems, raising their construction cost, commonly referred to as the cost premium, which strongly depends on the level of preparation and the implementation at the shipyard (Hu and Dong, 2024).

The aim of the present essay is to estimate the impact of the price premium for greening on newbuilding prices in the container liner shipping segment. This paper contributes to the existing literature by examining the following research question: What is the price premium associated with greening technologies for container vessels? Given the advanced technological requirements of alternative fuel-capable vessels, higher costs are anticipated. This study empirically evaluates individual new-building containership contracts from January 2010 to October 2024, offering insights into the cost implications of green technology adoption within the context of the IMO and EU decarbonisation targets. To do this, a four-step approach is followed Figure 5.1. In step 1, the paper reviews the existing literature to identify variables that impact new-building prices. For transparency and replicability, step 2 outlines the data collection, selection, and cleaning process, as well as the econometric approach employed. Step 3 illustrates the different variables for the analysis, step 4 provides the empirical result from the model, and the findings are discussed in the final step (step 5).

Figure 5.1: Research approach



The paper is structured as follows: Section 5.2 provides a literature review that addresses challenges in the container liner shipping industry, with a particular focus on the newbuilding market. Section 5.3 outlines the empirical methodology, and Section 5.4 describes the data. Section 5.5 presents the empirical analysis, while Section 5.6 discusses the findings. Finally, Section 5.7 concludes the study.

5.2 Literature Review

The new-building market, one of the key maritime markets identified by Stopford (2009), is where shipowners place orders for vessels that meet specific requirements unavailable in the second-hand market. Negotiations with shipyards involve vessel specifications, construction timelines (typically 1–3 years), and pricing, influenced by current market conditions and future expectations. The shipbuilding industry's cyclical and capital-intensive nature plays a crucial role, with prices fluctuating due to freight rates, production costs, shipyard capacity, and orderbook size. In addition, newbuilding prices reflect the balance between vessel demand and shipyard capacity. Demand drivers include freight rates, company profitability, and second-hand vessel prices, whereas supply-side factors include shipyard productivity, economic conditions, exchange rates, and governmental subsidies, all of which shape shipbuilding price behaviour (Stopford, 2009; Ferrari et al., 2018).

Past research has analysed supply and demand factors affecting newbuilding price formation, particularly in dry bulk and tanker markets. Haralambides et al. (2004) showed that higher charter rates, rising steel costs, exchange rates, and limited yard capacity increase newbuilding prices, while Mulligan (2008) identified the ship size (DWT) and the Producer Price Index (PPI) as primary determinants of newbuilding costs, with economies of scale reducing per-unit costs as vessel size increases. Xu et al. (2011) examined the dynamic relationship between international sea freight rates and newbuilding costs in the dry bulk market, indicating a one-way causal link where freight rates drive newbuilding prices, with a lag of 3–6 months, reflecting market inefficiencies. Moreover, Jiang and Lauridsen (2012) suggested that the time-charter rate is the most significant factor influencing shipbuilding prices, followed by shipbuilding costs, price-cost margins, and shipbuilding capacity utilisation, whereas Adland et al. (2017) suggested that while market conditions and GDP per capita significantly influence pricing, the heterogeneity among shipyards and shipowners also plays a crucial role in determining the US-dollar cost per compensated gross tonne (US$/CGT). In a related study, Syriopoulos et al. (2021) developed a Support Vector Regression (SVR) model to forecast newbuilding ship prices, demonstrating that machine learning models outperform traditional forecasting methods, emphasising the nonlinear nature of price dynamics. Alblas and Pruijn (2024) also reviewed shipbuilding cost estimation methods for Engineering-To-Order (ETO) projects, assessing their suitability in the context of the energy transition and technological advancements, demonstrating that existing methods relying on expert judgment and historical data are inadequate, highlighting the need for an integrated framework that aligns cost estimation with modern construction processes.

On top of that, environmental considerations have become increasingly influential in new building investments. Haehl and Spinler (2018) analysed how regulatory uncertainty affects capacity expansion, showing that firms prefer flexible strategies like chartering when facing unclear environmental policies, while Kokosalakis et al. (2021) assessed how IMO environmental regulations influence compliance and fuel efficiency, finding that energy-efficient vessels with scrubbers have higher market value and are more likely to comply. Ammar and Seddiek (2020) also explored the emission reduction strategies, demonstrating that dual-fuel engines and speed reduction significantly improve EEDI scores while providing substantial cost savings.

Furthermore, academic research has also examined the potential of alternative fuels adoption, with LNG being widely studied as a transitional fuel due to its regulatory advantages, despite concerns over methane slip. Schinas and Butler (2016) and Zhang et al. (2021) highlighted LNG's benefits in meeting emissions regulations, while Jeong and Yun (2023) showed that while LNG and VLSFO have comparable profitability without carbon pricing, LNG’s relative competitiveness improves significantly under market-based measures such as the EU Emissions Trading System (EU ETS), due to its lower carbon intensity and reduced fuel consumption. In contrast, ammonia remained economically unviable, primarily because of its substantially higher daily fuel consumption, lower energy density, and greater exposure to fuel price volatility. Nevertheless, Horvath et al. (2018) and Xing et al. (2021) supported methanol’s near-term feasibility, while Adami and Figari (2024) noted its suitability for smaller vessels. Similarly, Zou and Yang (2023) show that alternative fuels can cut SO_x by approximately 99% and NO_x by 75–90%, with hydrogen, ammonia, and methanol being the most promising options to reduce emissions, and they argue that scrubbers-fitted vessels remained the most cost-effective option under alternative fuel price scenarios, while when the price gap between alternative fuel and traditional fuels narrows, the alternative fuel selection becomes optimal, with hydrogen providing both economic and environmental benefits. However, it is suggested that only green hydrogen and green ammonia achieve deep lifecycle GHG reductions, but without carbon pricing or incentives, their high costs and limited supply restrict their competitiveness, while ammonia also requires NOx and N_2O control systems (Zou and Yang, 2023).

Recent studies have also explored the capital cost differentials between alternative fuel vessels and their conventional counterparts. Wang et al. (2021) conducted a life-cycle cost evaluation of LNG dual-fuel container ships and found an average 24–29% higher capital cost compared to conventional ships, primarily because LNG-ready ships must carry vacuum-insulated cryogenic tanks, double-barrier fuel lines, vaporisers, and extensive gas-handling and safety systems, increasing their capital costs. Similarly, Maersk Mc-Kinney Moller Center (2022) reported a smaller but still higher capital cost of roughly 11 % for e-methanol and 16 % for e-ammonia compared to conventional fuel ships, reflecting the fact that methanol storage relies on coated, ambient-temperature mild-steel tanks and simpler piping and that methanol-ready engines require lower capital cost than high-pressure LNG dual-fuel ships. Building on broader market observation, Moutzouris et al. (2024) applied a hedonic panel model to more than 4,300 newbuilding and resale transactions for tanker and dry bulk carriers and reported an average 25% price premium for eco-vessels compared to conventional counterparts, with their income premia ranging between 9% and 15% higher, suggesting that this price premium was higher in weak freight markets and was driven mainly by past price trends, charter-rate differences, and the growing share of eco-ships. Lastly, Jia et al. (2024) indicated that eco-containerships were traded approximately 20% higher than their conventional counterparts, with financial buyers, who typically act as lessors, preferring to invest in eco-ships compared to operating buyers, while Georgoudakis et al. (2025) found that 1% increase in energy efficiency leads to a 0.10% to 0.12% increase in daily time-charter rates for containerships, and this premium was stronger for eco-engine vessels, reaching 0.18% to 0.22% per 1% EEDI improvement.

Overall, these studies highlight that eco-vessels benefit from both higher resale values and better time-charter earnings, reflecting a growing market appreciation for environmentally efficient designs, which influence future investment decisions, reinforcing the shift toward greener shipping solutions. Therefore, it is evident that as shipowners aim to meet the IMO and EU decarbonisation regulations, the choice of vessel specifications and fuel technologies has become a critical consideration, directly influencing newbuilding prices. Furthermore, while previous research has analyzed elements impacting new-building prices, the cost premium related to alternative fuel containerships remains limited, with the focus mainly on the dry bulk and tanker sectors. This study empirically addresses the research gap related to the cost premium for alternative fuel technologies by analysing real data transactions on new-building contracts for the container shipping market.

5.3 Empirical Methodology

The second step in the research is collecting and selecting variables for the regression model, cleaning data that do not provide full information related to the study, and assessing their expected impact on newbuilding prices. The section also provides the regression model used in the empirical part of this study.

5.3.1 Data Collection

To analyse the impact of greening on the newbuilding prices for containerships, a dataset with individual newbuilding contracts was provided by Alphaliner, a leading shipping industry intelligence platform that specialises in providing detailed data, analysis, and news on the container shipping market, covering the period from January 2010 to October 2024. It includes details such as the contract date, ship name, IMO number, build year, vessel specifications (vessel capacity in twenty-foot equivalent units (TEUs), deadweight (DWT), and gross tonnage (GT), and fuel type, shipyard name and location, the delivery date, and the shipowner.

5.3.2 Data Selection and Cleaning

The initial sample comprised 2,897 observations. After excluding contracts that lacked information on newbuilding prices (1,189 observations), the final dataset consisted of 1.708 observations, including all the important information of the analysis, representing 58% of the total order book. Additionally, the final sample included data from 73 shipyards and 150 container shipping owners. Table 5-1 summarises the variables used in the analysis, as well as their interpretation and the expected sign of the coefficients.

Table 5-1*: Data descriptions and expected coefficients*

Dependent Variable	Units	
New-building Prices (NB)	(Millions USD $)	
Independent Variables	**Units and interpretation**	**Expected coefficients**
<u>Vessel characteristics</u>		
GT	Vessel capacity in Gross Tonnage (Tonnes)	+
Vdesign	Designed speed serves as a proxy for the size of the main propulsion engines (knots)	+
Scrubbers	Dummy variable for vessels able to operate with IFO-380 Fuel and are equipped with scrubbers	+
$FUEL_{ALT}$	Dummy variable for vessels equipped with any alternative fuel	+
LNG	Dummy variable for vessels able to operate with LNG fuel	+
Methanol	Dummy variable for vessels able to operate with Methanol fuel	+
Hybrid	Dummy variable for vessels able to operate with other types of alternative fuels	+
Reference fuel category	VLSFO (Very Low Sulfur Fuel Oil)	
<u>Shipyard location</u>		
DChina	Dummy variable for vessels built in China	-
DJapan	Dummy variable for vessels built in Japan	+
Reference Region	The Republic of Korea	

Following Table 5-1, variables used to describe the vessel specification were summarised under the vessel characteristics. Starting with the ship's size, the Gross Tonnage (GT) was used as a variable to measure the size of the vessel and, therefore, the amount of steel needed. Since shipbuilding costs scale with vessel size, GT directly reflects material and labour requirements, making a positive relationship with newbuilding prices. Moreover, the designed speed (in knots) of the vessel was used to capture the vessel's hull size and its technical sophistication. Higher speeds are typically linked with higher fuel consumption, more powerful engines, optimised hull designs, and advanced fuel efficiency technologies, all of which can influence construction costs.

Additionally, to account for different fuel operations, containerships designed to run on IFO 380 and are equipped with scrubbers were identified using the (Scrubbers) dummy variable, while vessels operating under Very Low Sulfur Fuel Oil (VLSFO) were captured using a separate dummy variable (VLSFO). These dummy variables represent containerships that can operate exclusively with those fuel types. Moreover, vessels capable of using any alternative fuels such as LNG, methanol, hydrogen, biofuels, or other alternatives were classified under the ($FUEL_{ALT}$) dummy variable. To enhance the analytical depth of the study, containerships specifically designed and ready to operate on LNG were distinguished using the dummy variable (LNG), while those designed for methanol were categorised under the (Methanol) variable. It is important to note that LNG and Methanol dummy variables refer to vessels capable of running on conventional fuels (VLSFO or IFO 380) and a single alternative fuel (LNG or methanol), respectively. In contrast, ships designed to operate on multiple alternative fuels, such as LNG and methanol, or combinations including hydrogen, biofuels, or ammonia, were classified under the (Hybrid) dummy variable, representing vessels with enhanced fuel flexibility and adaptability to evolving fuel technologies.

To capture the location effect of shipyards, including factors such as governmental subsidies, shipyards were categorised based on their location using dummy variables. Specifically, shipyards situated in China were represented by the dummy variable (DChina), those in the Republic of Korea (Rep. Korea), and those in Japan (DJapan). These variables allow for an analysis of potential differences in newbuilding prices and shipbuilding practices across the three dominant shipbuilding nations. Given that China, the Republic of Korea, and Japan collectively dominate the global shipbuilding market, these regional classifications help capture variations in production costs, technological expertise, labour efficiency, and government support policies that may influence contract pricing and shipyard competitiveness. Using Republic of Korea as the reference category, the DChina dummy is expected to have a negative coefficient, as Chinese shipyards generally offer lower newbuilding prices due to lower labor costs, economies of scale, and strong governmental support, while the DJapan dummy is expected to have a positive coefficient, reflecting Japan's higher production costs, specialised vessel focus, and has a relatively protected domestic equipment market, which limits price competition and raises input costs (Jiang et al., 2013). Furthermore, to address unobserved heterogeneity across shipyards as well as macroeconomic fluctuations, the analysis incorporates a two-way fixed-effects specification, absorbing both shipyard-specific and year-specific effects. This ensures that persistent structural differences among shipyards and temporal shocks in the broader market do not bias the estimated relationship between vessel characteristics and newbuilding prices.

All contract prices were adjusted to 2024 levels using the U.S. Consumer Price Index (CPI) to account for inflation, ensuring comparability across contracts and isolating price variations driven by vessel characteristics, shipyard capabilities, and market conditions. The specific index was used following a similar approach to Jiang et al. (2013) and Adland et al. (2017). Lastly, this analysis excludes supply-side variables such as shipyard capacity, size, experience, labour, and operational costs, as well as demand-side factors like shipowner size, market expectations, second-hand prices, and fleet size, which have been considered in previous studies. The primary reason is that the focus of the study remains on assessing the impact of greening on new building prices by emphasising vessel-specific characteristics, such as gross tonnage (GT) and designed speed, along with alternative fuel adoption and shipbuilding location. Additionally, dummy variables for fuel type, contracting time, and shipbuilding region (or shipyard dummies) help capture potential variations in pricing trends, technological adoption, and regulatory impacts.

5.3.3 Regression Model Selection

To estimate the cost premium for greening on containership newbuild prices, a panel technique is used, accounting for both time and location-specific effects. Two econometric models are used to ensure robustness in the estimation of price determinants: (i) a pooled OLS model incorporating country-level effects and time-fixed effects, and (ii) a two-way fixed-effect models that rely on within-variation at the shipyard level.

5.3.3.1 Pooled OLS With Country and Time Fixed Effects

In the first model, a pooled OLS regression is used to control for regional effects by including dummy variables for shipbuilding countries (China, Japan, Republic of Korea) along with time-fixed (years) effects. The inclusion of country and year fixed effects captures macro-level differences arising from regulatory policies, industrial structures, and broader economic conditions.

To estimate the impact of the cost premium for greening on new building prices, the following pooled OLS regression models were conducted:

$$\ln(NB_{it}) = \beta_0 + \beta_1 * \ln(GT_i) + \beta_2 * \ln\left(V_{design_i}\right) + \beta_3 * FUEL_{ALT,i} + \beta_4 * scrubbers_i + \sum_{j=0}^{2} \beta_{8+j} * Yardcountry_{ij} + \sum_{t=1}^{13} \beta_{10+t} * Year_t + u_{it} \qquad \textit{Eq. 5-1}$$

Where:

- ln(NB_{it}) represents the logarithmic transformation of the New building prince of vessel i with contract made on year t
- βo is the intercept.
- β_1 ,,β_2 ,β_3,... are the coefficients for the independent variables.
- ln(GT_i) refers to the logarithmic transformation of the Gross Tonnage
- ln($V_{design,i}$) indicates the designed speed of the vessel i
- $Scrubbers_i$ is a dummy variable for vessels equipped with scrubbers and operating under IF0-380
- $Fuel_{ALT,i}$ is a dummy variable for vessels able to operate with any alternative fuel, (regardless of the specific fuel type), and 0 for conventional-fuel vessels (VLSFO or IFO-380).

- $\sum_{t=0}^{13} Year_t$ includes time-fixed effects (yearly)

- $\sum_{j=1}^{2} yardcountry_{ij}$ presents country-level dummies for the country in which the vessel is built.

- u_{it} are the idiosyncratic errors

Building on Eq. 5-1, the second equation disaggregates the overall alternative-fuel indicator into specific fuel types (LNG, Methanol, Hybrid), allowing technology-specific cost premiums while keeping countries and time-fixed effects:

$$\ln(NB_{it}) = \beta_0 + \beta_1 * \ln(GT_i) + \beta_2 * \ln\left(V_{design,i}\right) + \beta_3 * LNG_i + \beta_4 * Methanol_i + \beta_5 * Hybrid_i + \beta_6 * scrubbers_i + \sum_{j=0}^{2} \beta_{8+j} * Yardcountry_{ij} + \sum_{t=1}^{13} \beta_{10+t} * Year_t + u_{it} \quad \text{Eq. 5-2}$$

Eq. 1 and Eq. 2 introduce country-level controls to account for broader regional factors that may influence pricing, such as government policies, environmental regulations, and macroeconomic conditions. This approach allows for the estimation of country-level differences in new building prices while keeping shipyards as the cross-sectional units. However, they do not capture unobserved, time-invariant heterogeneity at the shipyard level.

5.3.3.2 Two-Way Fixed Effects Model Controlling for Time and Shipyard Individual Characteristics

To strengthen the empirical analysis, a robustness check is performed using a two-way fixed-effects (FE) method. This approach controls for unobserved heterogeneity both across time and shipyards. Shipyards fixed effects (α_s) capture persistent differences, differences across builders, such as productivity, technological specialisation, or labour cost structures, while year fixed effects capture macroeconomic shocks and regulatory changes that are common to all shipyards in a given year.

The two-way fixed-effects specifications are given as:

$$\ln(NB_{ist}) = \beta_0 + \beta_1 * \ln(GT_i) + \beta_2 * \ln(V_{design,i}) + \beta_3 * FUEL_{ALT,i} + \beta_4 * scrubbers_i + \sum_{t=1}^{13} \beta_{5+t} * Year_t + \alpha_s + u_{ist} \quad \textit{Eq. 5-3}$$

$$\ln(NB_{ist}) = \beta_0 + \beta_1 * \ln(GT_i) + \beta_2 * \ln(V_{design,i}) + \beta_3 * scrubbers_i + \beta_4 * LNG_i + \beta_5 * Methanol_i + \beta_6 * Hybrid_i + \sum_{t=1}^{13} \beta_{7+t} * Year_t + \alpha_s + u_{ist} \quad \textit{Eq. 5-4}$$

Here, β_0 represents the intercept for the reference shipyard in the baseline year, while the coefficients (β_1 , $\beta 2$,$\beta 3$,...) capture the estimated marginal effects of the main independent variables, as described in Eq. 5-1 and Eq. 5-2, respectively. The term α_s represents shipyard fixed effects (absorbing any shipyard-specific characteristics), $Year_t$ represents the year dummies to control time variations, while u_{ist} represents the idiosyncratic error term. In practice, the fixed effects (FE) estimator relies on the within transformation, known as demeaning, which eliminates time-invariant unobserved heterogeneity by subtracting individual means from the variables (Wooldridge, 2010).

For shipyard s in year t, the transformed model becomes:

$$y_{it} = a_i + x_{it}\beta + u_{it} \rightarrow y_{it} - \ddot{y}_{st} = (\mathrm{x}_{\mathrm{st}} - \ddot{x}_{st})\beta + (u_{st} - \ddot{u}_{st}) \quad \textit{Eq. 5-5}$$

Where $\ddot{\boldsymbol{y}}_{\boldsymbol{s}}$ and $\ddot{\boldsymbol{x}}_{\boldsymbol{s}}$ are the shipyard-specific averages of the dependent and explanatory variables, respectively. This transformation ensures that estimation is based only on deviations from each shipyard's mean, thereby controlling for all time-invariant shipyard effects. The estimating equations then become:

$$\ln(\widetilde{NB_{\iota t}}) = \beta_1 * \ln\widetilde{(GT_{\iota t})} + \beta_2 * \ln\widetilde{(GT_{\iota t})} + \beta_3 * \widetilde{FUEL_{ALT_{\iota t}}} + \beta_4 * \widetilde{scrubbers_{\iota t}} + \widetilde{U_{\iota st}} \quad \textit{Eq. 5-6}$$

$$ln(\widetilde{NB_{\iota t}}) = \beta_1 * \ln\widetilde{(GT_{\iota t})} + \beta_2 * \ln\widetilde{(GT_{\iota t})} + \beta_3 * \widetilde{scrubbers_{\iota t}} + \beta_4 * \widetilde{LNG_{\iota t}} + \beta_5 * \widetilde{Methanol_{it}} + \beta_6 * \widetilde{Hybrid_{\iota t}} + \widetilde{U_{\iota st}} \quad \textit{Eq. 5-7}$$

where the tilde $\widetilde{(.)}$ denotes variables that have been demeaned across both shipyards and years.

The fixed-effects (FE) approach is preferred over random effects, as it allows for correlation between location-specific factors and explanatory variables, providing a more robust estimation of the relationship between green initiatives and new building prices (Wooldridge, 2010). All continuous variables were converted to logarithmic form for two primary reasons. First, applying a log transformation minimises the impact of outliers, enhancing the model's robustness and reducing sensitivity to extreme values. Additionally, it allows for the interpretation of coefficients in terms of proportional changes, effectively capturing multiplicative relationships. Second, the log-transformed variables improve the model's overall fit, as indicated by a higher R^2, demonstrating greater explanatory power. Furthermore, the transformation leads to better Durbin-Watson statistics, suggesting reduced autocorrelation in the residuals, which strengthens the reliability of the analysis (Greene, 2018). Finally, in all the regression models, robust standard errors were clustered at the shipyard level to account for heteroscedasticity and serial correlation. Additionally, the variance inflation factor (VIF) was used to assess multicollinearity. Finally, the coefficients on dummy variables are interpreted using the transformation "$(e^{\beta}-1)\times 100$" to express price effects as percentage premiums relative to the reference category.

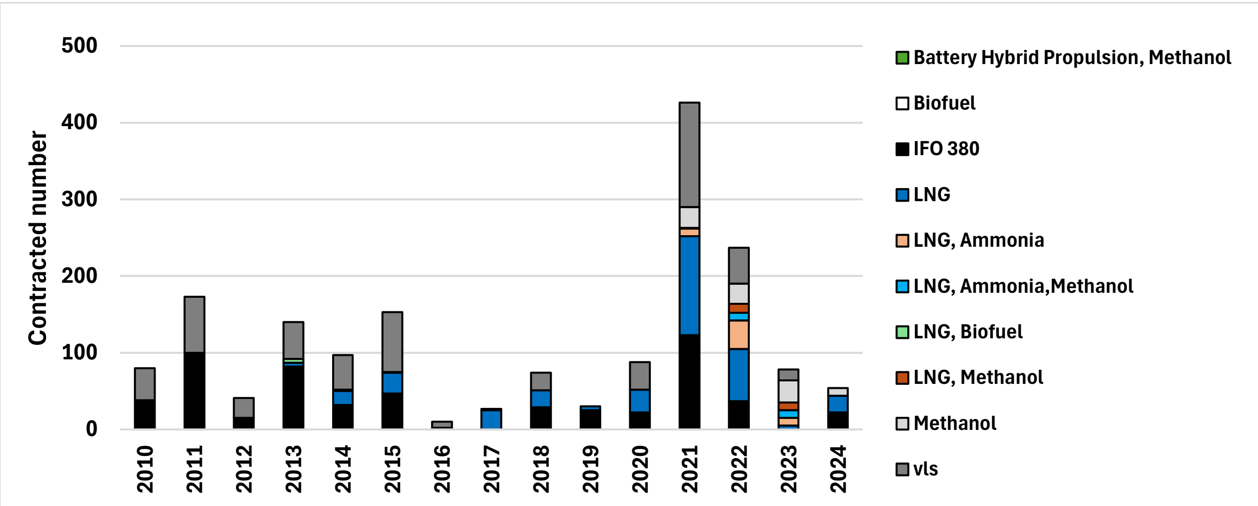
5.4 Data Visualisation

This section provides an overview of newbuilding contracts in the container liner shipping market, covering new building prices, vessel sizes, fuel types, and shipbuilding trends across major shipbuilding regions (China, the Republic of Korea, and Japan). It also presents descriptive statistics on gross tonnage (GT), designed speed, and pricing, offering insights into market dynamics and regulatory compliance in these key shipbuilding nations..

To this extent, Figure 5.2 presents the yearly distribution of newbuilding container vessel contracting numbers based on fuel type from January 2010 to October 2024, showing the gradual transition toward alternative, greener fuels. Initially, most containerships relied on conventional fuels like VLSFO or IFO-380, with a noticeable peak in the orderbook in 2011 and again in 2013. After 2020, however, alternative fuels gained traction. LNG quickly emerged as a preferred option, while methanol-fueled vessels also grew in importance before stabilising in recent years.

By 2024, conventional fuels still accounted for a notable share of orders, but dual-fuel designs had become increasingly common, including ammonia-methanol, LNG-ammonia, LNG-methanol, and hybrid battery combinations, reflecting shipowners' strategies to diversify across multiple fuel pathways. In contrast, biofuels remain marginal, with only four vessels contracted up to 2024, partly due to stricter technical and compliance requirements under ISO 8217:2024, as well as higher costs that demand long-term supply contracts and cost-sharing arrangements (CIMAC, 2024). The low orderbook numbers between 2016 and 2020 illustrate, to some extent, the uncertainty regarding upcoming IMO decarbonisation regulations and the weak market sentiment. During this period, conventional vessels dominated the limited contracts, though diversification into LNG and VLSFO was already emerging before the stronger shift toward alternative fuel adoption seen after 2020.

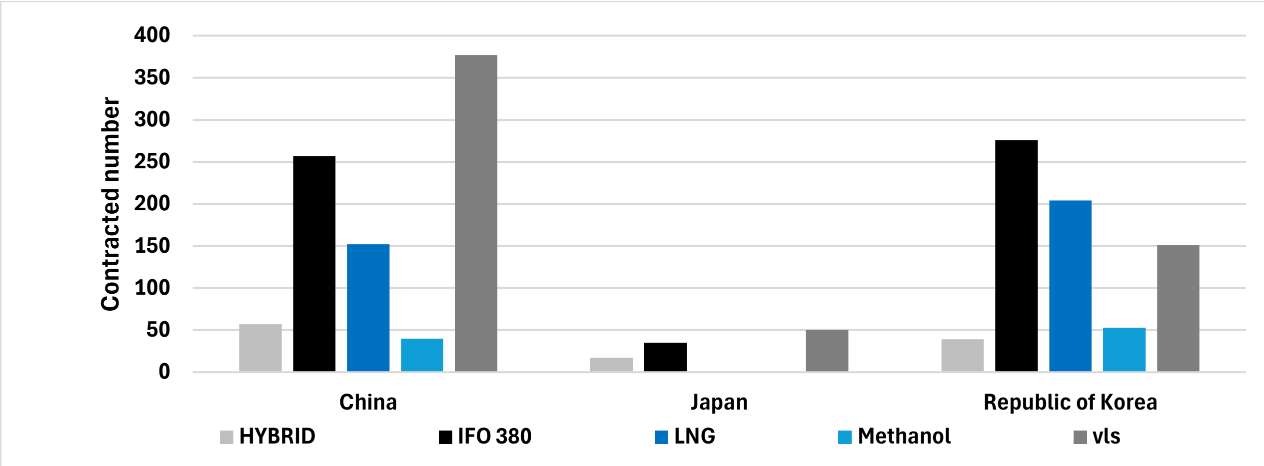
Figure 5.2: Containerships contracting order book by fuel type



Source: Own compilation based on the dataset provided by Alphaliner (2025)

Building on the trends observed in Figure 5.2, Figure 5.3, aggregates vessels utilising hybrid propulsion systems (e.g., LNG-methanol, LNG-ammonia, LNG-methanol-ammonia, battery-methanol, and biofuels) under the HYBRID category, due to the limited number of observations for such technologies. This broader classification ensures comparability across fuel types while reflecting the industry's growing diversification into alternative fuels. The dominance of conventional fuels (IFO 380, VLSFO) remains evident, particularly in China and the Republic of Korea, reflecting a historical reliance on traditional propulsion technologies. However, the adoption of LNG and methanol has increased, with the Republic of Korea and China leading this transition, particularly in these regions, aligning with the post-2020 shift toward lower-carbon solutions driven by stricter environmental regulations. Japan, although it has fewer overall orders, shows a strategic focus on bulk carriers, tankers, and niche vessel types that primarily rely on conventional fuels and hybrid propulsion, reflecting Japan's emphasis on high-specification, eco-friendly, and dual-fuel vessels (BRS Shipbrokers, 2025).

Figure 5.3: Containership's alternative fuel type order book by region from January 2010 to October 2024



Source: Own compilation based on the dataset provided by Alphaliner (2025)

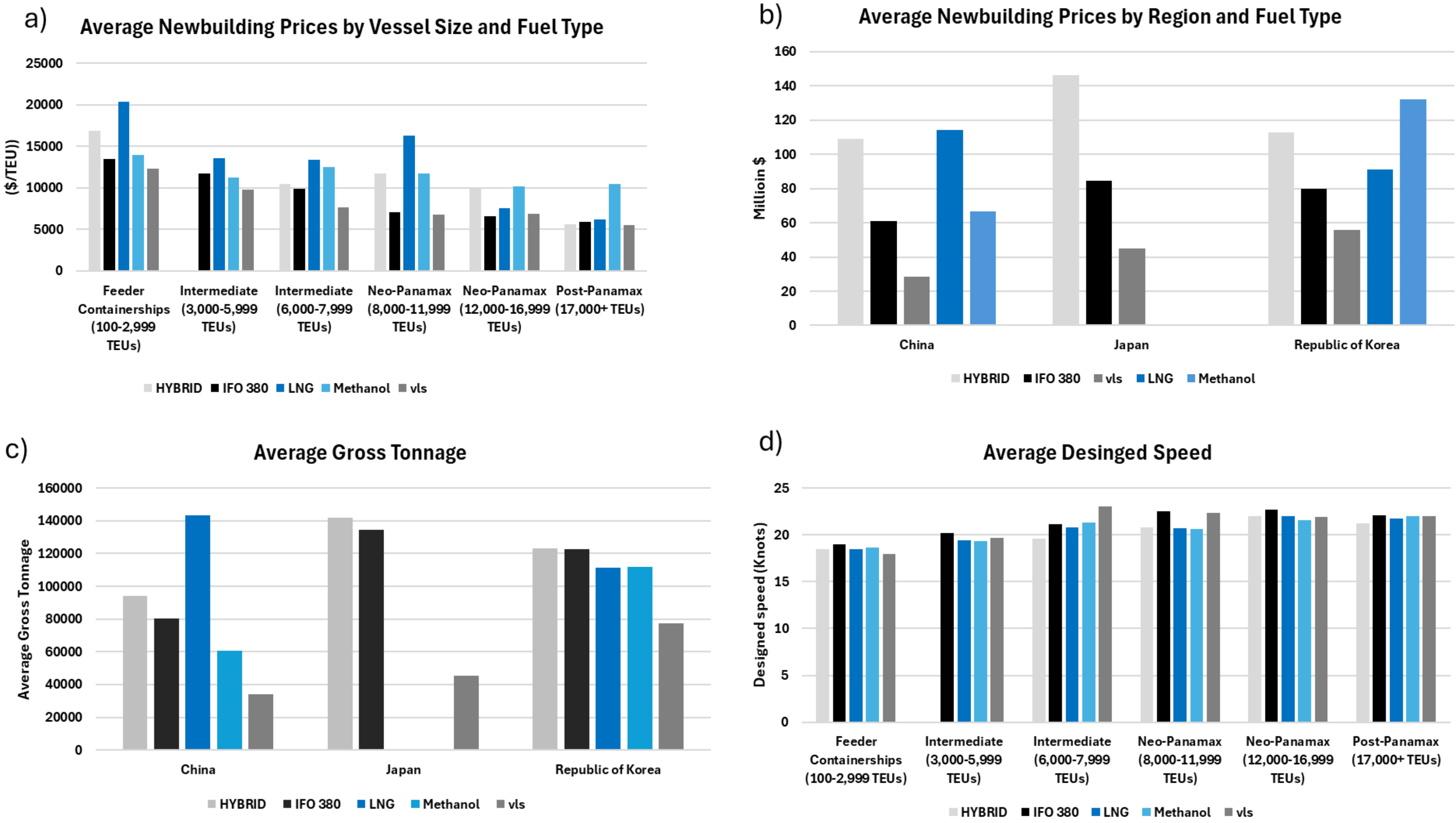
Figure 5.4 provides descriptive statistics and key trends in containership newbuilding prices, gross tonnage, and designed speed across different fuel types, vessel sizes, and regions. Graph (a) shows the average price per TEU ($/TEU) for containerships shows significant variations based on vessel size and fuel type. Feeder Containerships (100-2,999 TEUs) incur the highest costs across all fuel types, while larger vessels, such as Post-Panamax (17,000+ TEUs), benefit from economies of scale, record the lowest average price per TEU. Conventional fuels like IFO-380 and VLSFO remain the most cost-effective, particularly for larger vessels, while alternative fuels such as LNG, HYBRID, and Methanol command a premium, making alternative fuel adoption more financially challenging for smaller ships. Furthermore, Neo-Panamax and Intermediate containerships follow a declining cost trend as capacity increases, reinforcing the economic advantage through economies of scale. These trends suggest that while greener fuels are gaining traction, cost considerations remain a significant barrier, particularly for smaller containerships facing higher per TEU expenses.

Graph (b) highlights regional variations in newbuilding costs across China, the Republic of Korea, and Japan. It is shown that China remains the most cost-competitive for conventional fuels, but the costs rise significantly for LNG, HYBRID-powered vessels, and methanol-fueled ships, driven by the smaller contracted size (GT) compared to the Republic of Korea (graph c). Furthermore, the Republic of Korea presents a more balanced cost structure, with methanol-fueled vessels being the most expensive option, almost double the price compared to China. Japan reports newbuilding prices only for conventional IFO-380, VLSFO, and HYBRID vessels, suggesting that LNG and VLSFO-powered vessels are either absent from the dataset or not widely produced in Japan.

Graph (c) examines gross tonnage (GT) variations. In China, LNG and HYBRID vessels dominate the largest sizes, while VLSFO ships are the smallest. Japan's portfolio is concentrated on IFO 380 and HYBRID containerships, whereas Korea shows a more even GT distribution, with methanol, IFO 380, and HYBRID leading. Across regions, LNG and methanol vessels tend to exhibit higher GT values, which can be attributed to increased fuel storage capacity requirements and compliance with environmental regulations. This suggests China and Korea maintain diversified shipbuilding activities, while Japan focuses on larger conventional and hybrid vessels.

Finally, Graph (d) presents the designed speed. Feeder Containerships (100-2,999 TEUs) operate at the lowest speeds, with VLSFO-powered vessels being the slowest and IFO 380 the fastest vessel designs. As vessel size increases, speeds generally rise, with IFO-380- and VLSFO-powered vessels designed for higher speeds, while LNG- and Methanol-fueled ships tend to be designed at slightly lower speeds. However, vessel speed is also influenced by broader design trends, with earlier orders prioritising speed and later designs emphasising fuel efficiency and regulatory compliance.

Figure 5.4: Descriptive statistics on containership newbuilding contracts



Source: Own compilation based on the dataset provided by Alphaliner (2025)

Overall, Figure 5.4 highlights the cost, size, and performance interrelationships associated with newbuilding containerships. While alternative fuels such as LNG, HYBRID, and Methanol are being introduced in the market, they remain cost-intensive and can present operational challenges. Regional differences in pricing strategies and fuel preferences illustrate broader industry shifts toward greener technologies, yet traditional fossil fuels remain dominant in cost-sensitive market segments. The data further highlight the economic advantage of larger vessels, which benefit from economies of scale through lower TEU costs and provide higher operating speeds, reinforcing their competitive position in the market.

5.5 Empirical Results

To empirically assess the cost premium on newbuilding prices, firstly, a pooled OLS regressions are estimated to establish baseline relationships and capture regional and temporal effects. Secondly, a two-way fixed-effects approach is applied as a robustness check, accounting for unobserved heterogeneity across shipyards and common shocks over time.

5.5.1 Pooled OLS Estimates

To answer the research question, several regressions were conducted using EViews 10, allowing for a robust estimation of the impact of alternative fuel adoption and emission-reduction technologies on containership newbuilding prices. Table 5-2 shows the results for five distinct regression models.

Models 1 incorporate the two variables describing the vessel specification, namely the gross tonnage (GT), the designed speed (V_{design}) as noted in Table 5-1, while in Model 2, dummy variables were introduced to control for regional characteristics and time-specific effects. The inclusion of these dummy variables helps to account for the unique characteristics of specific periods and locations, thereby improving the model's accuracy and reducing potential biases. In this framework, the Republic of Korea serves as the reference region, with dummy variables included for China (DChina) and Japan (DJapan) to capture regional variations in new-building prices. Time-fixed effects are introduced through yearly fixed effects, controlling for macroeconomic fluctuations and regulatory developments over time. Model 3 estimates the cost premium associated with vessels adopting any type of alternative fuel, using as reference categories both VLSFO-fueled vessels and IFO-380 scrubber-fitted vessels, while Model 4 extends this framework by distinguishing between the dummy variables for alternative fuel adoption and those for exhaust gas treatment technologies (scrubbers), identifying the distinct cost premiums relative to VLSFO vessels. Specifically, the Alternative Fuels dummy ($FUEL_{ALT}$) takes the value 1 for all vessels equipped with any alternative fuel technology (e.g., LNG, methanol, or hybrid propulsion) and 0 for conventional-fuel vessels (VLSFO or IFO-380 with scrubbers). This variable captures the overall premium of alternative fuel adoption irrespective of the specific fuel type.

Furthermore, Model 5 presents the results from Eq. 2, disaggregating the alternative fuels into specific fuel types, and it enables a more granular analysis of price differentials across distinct alternative fuel technologies. For fuel type, vessels using Very Low Sulfur Fuel Oil (VLSFO) serve as the reference category, meaning the estimated coefficients for alternative fuel dummies and the vessels equipped with scrubbers and operating with IF0 380 reflect the price premium or discount relative to VLSFO-powered vessels. Given the log-linear specification of the dependent variable, the coefficients of these dummy variables are transformed using the exponential function $(e^{\beta}-1)\times 100$ to express the relative percentage change in new-building prices. A summary of these transformations and their respective effects is provided in Appendix A to ensure clarity and facilitate comparison across models.

Table 5-2: Empirical results from the regression models

Dependent variable $\ln(NB_{it})$					
	Regression Model 1	**Regression Model 2**	**Regression Model 3**	**Regression Model 4**	**Regression Model 5**
Vessel characteristics					
$\ln(GT_i)$	0.677 *0.011* (0.000)	0.628 0.013 (0.000)	0.605 0.013 (0.000)	0.599 0.013 (0.000)	0.598 0.013 (0.000)
$\ln(Vdesign_i)$	0.512 *0.091* (0.000)	0.999 0.130 (0.000)	0.961 0.122 (0.000)	0.918 0.120 (0.000)	0.930 0.119 (0.000)
$FUEL_{ALT}$			0.201 0.017 (0.000)	0.235 0.020 (0.000)	
Scrubbers				0.053 0.010 (0.000)	0.054 0.010 (0.000)
LNG					0.255 0.021 (0.000)
Methanol					0.168 0.023 (0.000)
Hybrid					0.210 0.030 (0.000)
Location					
DChina		-0.124 0.011 (0.000)	-0.098 0.010 (0.000)	-0.094 0.009 (0.000)	-0.099 0.010 (0.000)
DJapan		-0.080 0.020 (0.000)	-0.004 *0.015* (0.755)	0.006 *0.016* (0.785)	0.002 *0.016* (0.875)
Constant	-4.993 *0.324* (0.000)	-6.098 0.285 (0.000)	-5.572 *0.267* (0.000)	-5.572 *0.267* (0.000)	-5.544 *0.273* (0.000)
Time-effects (Yearly)	No	YES	YES	YES	YES
R^2	0.841	0.934	0.943	0.943	0.944
Mean VIF	2.911	3.218	3.383	3.569	3.462
Number of observations	1,708	1,708	1,708	1,708	1,708

Values in italics are the clustered standard errors. Values in (.) are the p-values representing the statistical significance of the coefficients. Coefficients for all dummy variables were interpreted using the transformation$(e^{\beta}-1)\times 100$ to express their percentage impact on newbuilding prices (Ref. Appendix A).

The Republic of Korea is the reference country

Starting with Model 1, the results indicate that gross tonnage (ln(GT_i)) presents a strong positive causality with new-building prices, where a 1% increase in GT leads to a 0.67% increase in newbuilding prices. This effect remains positive and statistically significant across all models, with coefficients ranging from 0.60% to 0.67%, suggesting that larger vessels command higher prices. Similarly, designed speed (ln($V_{desing,i}$)) is positively associated with newbuilding prices, with a 1% increase in designed speed resulting in a 0.51% rise in newbuilding prices in Model 1 and 0.99% in Model 2. The greater magnitude observed when incorporating regional fixed effects (China and Japan, with the Republic of Korea as the reference) and time-fixed effects suggests that regional and time differences influence a vessel's new-building price. The increasing impact of design speed on newbuilding prices suggests that, after accounting for regional pricing differences, a higher design speed leads to higher prices not only due to the need for a larger engine but also because of factors such as enhanced hull design and more advanced propulsion systems, increasing their costs. Overall, including time and location fixed effects enhances the model fit, as reflected in an R^2 increase to 0.934, confirming that controlling for regional and time-specific factors improves the accuracy of the analysis.

Furthermore, Model 3 shows that vessels utilising any alternative fuel technologies (regardless of which alternative technology LNG, methanol or hybrid), compared to those operating on Very Low Sulfur Fuel Oil (VLSFO) or scrubber-equipped ships operating with IFO-380, as the reference categories, exhibit a price premium of approximately 22.26%. While gross tonnage and designed speed remain key pricing determinants, their coefficients slightly decrease, indicating that part of the vessel price differentiation is now attributed to alternative fuel technology rather than conventional vessel specifications. Building on this, Model 4 differentiates between vessels that adopt alternative fuels and those equipped with exhaust gas treatment technologies (scrubbers), which aim at reducing sulfur oxide (SO_x) emissions. In Model 4, VLSFO vessels serve as the reference category. The results indicate that vessels fitted with scrubbers (scrubbers) command a moderate but statistically significant cost premium of 5.44%, confirming that emission control systems contribute to vessel price. Additionally, the premium for alternative fuel adoption rises to 26.49%, further reinforcing the increasing influence of energy-efficient and environmentally compliant vessel specifications on ship pricing. The R^2 remains high at 0.943, indicating strong explanatory power and further validating the model's ability to capture the key determinants of new-building prices.

Model 5 refines the analysis by differentiating between specific alternative fuel types, with VLSFO serving as the reference point. The results confirm substantial price premiums for each fuel technology, with LNG-powered vessels commanding the highest cost premium of 29.05%, methanol-powered vessels commanding an 18.29% cost premium, and hybrid-powered vessels having a premium of 23.37%, compared to VLSFO vessels. These findings highlight that vessels' technical specifications provide different price variations, with LNG being the highest valued among alternative fuels. Additionally, the scrubber premium remains stable at 5.55%, indicating that scrubber-fitted vessels require higher upfront capital investment for exhaust gas cleaning systems.

Moreover, across Regression Models 2 to 5, the inclusion of regional dummies reveals notable pricing differences. Vessels built in China consistently exhibit a price discount compared to the Republic of Korea, with coefficients ranging from -8.97% to -11.66%, reflecting lower production costs in Chinese shipyards. Meanwhile, the effect for the Japan region diminishes from an initial -7,68% in Model 2 to a positive but insignificant 0.20% in Model 5, suggesting that after accounting for vessel specifications and fuel technologies, the price gap between Japan and the Republic of Korea shipyards becomes statistically insignificant, whereas the price differential between China and the Republic of Korea remains significant. This also suggests that there is a significant price difference between China and the Republic of Korea, with China providing substantially lower prices.

Finally, the R^2 values improve significantly across models, from 0.84 in Model 1 to 0.94 in Models 3, 4, and 5, indicating that incorporating the region and the time effects, together with the alternative fuel and emission reduction technologies, enhances model accuracy. Without incorporating fixed effects, the mean VIF values range from 2.705 to 2.906 on average, indicating that multicollinearity is not a significant concern in the overall model. However, when introducing dummies for regional-fixed effects and time-fixed effects, the

VIF values increase substantially, suggesting that these fixed effects are highly correlated with other explanatory variables (GT, V_{design}), likely due to structural patterns in the data, such as regional differences in vessel characteristics or temporal trends affecting shipbuilding decisions (ref. Appendix B). The results confirm that alternative fuel vessel designs and emission control technologies command significant price premiums, with LNG systems being the most expensive option among other fuel alternatives. Additionally, there are noticeable regional price disparities, with Chinese shipyards consistently exhibiting lower prices compared to global competitors.

5.5.2 Two-Way Fixed Effects Estimates

To re-evaluate the results from the pooled OLS regression, Table 5-3 presents the results from the two-way fixed effects models, where shipyards serve as the cross-reference units, allowing for a more comprehensive assessment of the determinants of new-building prices while controlling for shipyard-specific characteristics. This addresses potential biases in the pooled OLS regression by accounting for unobserved heterogeneity at the shipyard level.

Table 5-3: Empirical results from the regression models

Dependent variable $\ln(NB_i)$					
	Regression Model 1	**Regression Model 2**	**Regression Model 3**	**Regression Model 4**	**Regression Model 5**
Vessel characteristics					
$\ln(GT_i)$	0.677 *0.013* (0.000)	0.595 0.027 (0.000)	0.557 0.026 (0.000)	0.548 0.027 (0.000)	0.549 0.027 (0.000)
$\ln(Vdesign_i)$	0.512 *0.142* (0.000)	0.671 0.138 (0.000)	0.653 0.125 (0.000)	0.616 0.122 (0.000)	0.618 0.120 (0.000)
$FUEL_{ALT}$			0.208 0.019 (0.000)	0.224 0.024 (0.000)	
Scrubbers				0.054 0.014 (0.000)	0.055 0.014 (0.000)
LNG					0.266 0.025 (0.000)
Methanol					0.178 0.027 (0.000)
Hybrid					0.213 0.033 (0.000)
Constant	-4.993 *0.324* (0.000)	-4.816 0.346 (0.000)	-4.348 *0.330* (0.000)	-4.164 *0.335* (0.000)	-4.181 *0.328* (0.000)
Time-effects (Yearly	No	YES	YES	YES	YES
Shipyards Fixed effects	No	YES	YES	YES	YES
R^2	0.841	0.950	0.958	0.956	0.956
Mean VIF	2.838	3.376	3.159	3.613	3.439
Number of observations	1,708	1,708	1,708	1,708	1,708

Values in italics are the clustered standard errors.

Values in (.) are the p-values representing the statistical significance of the coefficients.

Coefficients for all dummy variables were interpreted using the transformation(eβ-1)×100 to express their percentage impact on newbuilding prices (ref Appendix D)

The results confirm that gross tonnage ($\ln(GTi)$) remains a primary determinant of new-building prices, with a consistent positive effect across all models, ranging between 0.55% and 0.68%, confirming that ship size continues to drive new-building pricing. Similarly, designed speed ($\ln(V_{desing,i})$) exhibits a positive impact, with a 0.51% increase in new-building prices, and its cause rises to 0.67% in Model 2 after incorporating time-fixed effects and shipyard-fixed effects. With the inclusion of alternative fuel adoption ($FUEL_{ALT}$) in Model 3, the results show that vessels utilising alternative fuels receive a cost premium of 23.12% over vessels relying on conventional fuels (VLSFO/IFO 380). This premium rises to 27,76% in Model 4, where scrubber-equipped vessels (scrubbers) are explicitly controlled for, commanding a 5,65% premium, with VLSFO being the reference category. Lastly, in Model 5, findings reveal that LNG-powered vessels command a 30.47% cost premium, with hybrid-powered vessels following with a 23,86% cost premium, while methanol-powered vessels exhibited the lowest cost premium among alternative fuel vessels at 19%. Additionally, IFO-380 scrubber-equipped vessels continue to exhibit a statistically significant cost premium of 5.65% compared to VLSFO-powered containerships.

Overall, including shipyard-fixed and time-fixed effects significantly enhances model precision, as evidenced by an increase in R^2 from 0.841 in Model 1 to 0.956 in Models 2-5. The substantial changes in coefficients are primarily driven by the inclusion of shipyard-fixed effects and time-fixed effects, which account for pricing variations, technological capabilities, and cost structures across shipyards, leading to more precise estimates of alternative fuel premiums. Additionally, shifting from regional to shipyard-specific effects isolates microeconomic factors, refining the true impact of fuel technology on vessel pricing. Furthermore, multicollinearity remains low (VIF between 2.83 and 3.60, ref. Appendix E), ensuring the robustness and reliability of the estimated coefficients.

5.6 Discussion

The containership newbuilding market is undergoing a structural transformation driven by stricter environmental regulations, influenced by the IMO and EU decarbonisation targets, rising fuel costs, technological advancements, and shifting investment preferences toward more energy-efficient vessels. Consistent with previous studies that identified substantial cost premia for eco- and alternative-fuel vessels, ranging from 20–25% in tanker and bulk markets (Jia et al., 2024; Moutzouris et al., 2024) to 24–29% for LNG-fueled containerships (Wang et al., 2021), the present analysis confirms that alternative-fuel vessels in the containership segment command significant cost premiums relative to conventional VLSFO-fueled containerships.

The regression results from regional-fixed and time-fixed effects (Table 5 -2) confirm that alternative fuel vessels command a significant cost premium of 22,26% - 26,49% over conventional vessels (VLSFO/IFO 380). Specifically, LNG-fueled vessels exhibit the highest price premium (29.05%), followed by hybrid-fueled (23.37%) and methanol-fueled vessels (18.29%), relative to conventionally fueled (VLSFO) containerships. In addition, vessels equipped with exhaust gas treatment technologies, such as scrubbers, exhibit a moderate price premium of approximately 5,55%. While the model does not explicitly distinguish the scrubber type (i.e open-loop, closed-loop, or hybrid scrubber systems), results align with evidence that scrubber adoption requires a higher up-front cost, but remains a cost-effective short-term compliance strategy for shipowners, driven by fuel price differentials and anticipated regulatory pressures (X. Zhang et al., 2021; Drewry, 2024).

The study also highlights significant regional cost variations in containership new-building prices. Vessels constructed in China are approximately 9.34% cheaper than those built in the Republic of Korea or Japan, reflecting labour costs, government subsidies, and higher production efficiencies at Chinese shipyards. By contrast, the price gap between Japan and the Republic of Korea is statistically insignificant once vessel specifications and fuel technologies are controlled for. These findings are consistent with prior studies highlighting China’s competitive cost advantage in shipbuilding (Jiang et al., 2013; Hess et al., 2020). Jiang et al. (2013) also showed that while China has historically maintained a cost advantage over the Republic of Korea and Japan, rising labour costs and shipping equipment expenses could erode this edge. According to USTR (2025) China’s state-backed policies have also driven its shipbuilding market share from under 5% in 1999 to over 50% in 2023, distorting competition. In response, U.S. policymakers are considering measures such as port fees on Chinese-built vessels to counteract these effects, reflecting broader economic and security concerns in the maritime industry, with future research needed to provide a deeper explanation regarding China's competitiveness, including the US shipyards, among others.

Furthermore, the shipyard- and time-fixed effects analysis (Table 5-3) further refines the cost premiums for alternative fuel containerships. LNG vessels are about 30,47% more expensive than VLSFO, methanol 19%, and hybrid vessels 23,86%, while the overall alternative fuel cost premium remains at approximately 23,12% - 27,76% more expensive compared to VLSFO containerships when the scrubbers-equipped vessels are counted for. The shift from regional to shipyard-specific fixed effects confirms that green technology valuation is independent of shipyard location, with shipowners required to pay extra costs driven by regulatory and technological factors rather than regional cost variations. These cost premiums suggest that shipowners are required to bear higher capital expenditures for vessels designed to comply with decarbonisation regulations, and they support prior studies indicating that more energy-efficient vessels require substantial premiums compared to conventional counterparts (Dirzka and Acciaro, 2021; Jia et al., 2024; Georgoudakis et al., 2025).

From a market perspective, shipowners investing in alternative-fuel vessels to comply with IMO and EU regulations shall account for the associated cost premiums, which not only reflect the greening requirements but also enable them to strategically position their fleets against future market uncertainties. The substantial cost premiums for LNG, methanol, and hybrid vessels indicate that shipowners must bear these additional costs to comply with emissions regulations while potentially benefiting from fuel-efficient and potentially lower emission ship operations. However, this study focuses solely on new-building prices and does not account for running and voyage costs, which also play a crucial role in long-term investment strategies. For shipyards, these findings suggest the necessity of expanding expertise in shipbuilding construction and maintaining cost competitiveness. As alternative fuel vessels continue to gain traction, shipbuilders must adapt by incorporating advanced propulsion technologies, optimising hull designs, and ensuring compatibility with evolving fuel infrastructure. The observed cost premiums for greening suggest that policy interventions such as subsidies or tax incentives may reduce the financial burden of green transitions and accelerate decarbonisation efforts in the shipbuilding industry.

Despite these valuable contributions, this study also presents opportunities for further exploration. First, to maintain simplicity, the analysis focuses on core indicators and excludes additional explanatory variables such as macroeconomic factors, including steel prices, interest rates, global trade volumes, and fuel price volatility. While these variables could offer a more comprehensive view of the newbuilding price formation, they are largely captured through fixed effects and vessel category dummies. Notably, containership newbuilding prices between 2021 and 2024 (see Appendix B, D) were significantly higher than in earlier years, suggesting the need for further analysis of market fluctuations. Second, factors such as shipowners' negotiation power, market expectations, and second-hand vessel prices, though potentially influential, are assumed to be absorbed by the fixed effects. Similarly, shipowner preferences and strategic motivations (e.g., long-term operational costs, market positioning, and sustainability goals) are not explicitly modelled.

Future research should examine how macroeconomic factors such as interest rates, fuel price volatility, and global trade patterns affect shipowners’ investment decisions. Additionally, analysing how freight rates and second-hand market prices respond to green investments could yield important insights for shaping newbuilding strategies. A deeper investigation into regional competitive dynamics, production efficiencies, and government support measures would offer valuable guidance for shipyards. Furthermore, geopolitical developments, including the potential return of protectionist policies under a second

Trump administration, may alter the global shipbuilding landscape. In particular, renewed efforts in the United States to revitalise domestic ship production and reduce dependence on Asian shipyards could impact market competitiveness and regulatory frameworks (USTR, 2025). Therefore, understanding how such shifts influence investment in sustainable ship technologies will be critical for stakeholders across the maritime industry.

5.7 Conclusions

This study provides empirical evidence that greening significantly influences new-building prices in the containership sector. The results confirm that alternative fuel vessels command a substantial price premium over conventionally fueled ships, with LNG, methanol, and hybrid-fuel containerships priced at 29,05%, 18,29%, and 23,37% higher than VLSFO-fueled vessels, respectively. The overall alternative fuel cost premium remains at approximately 22,26%, reinforcing the increasing cost burden to comply with regulatory targets and sustainability in shipowner investment decisions.

The research also highlights key regional price differences, confirming that China maintains a financially competitive advantage of 9.34% over the Republic of Korea and Japan. However, the decision to order a containership in Japan or the Republic of Korea appears negligible in terms of price differentials, as no significant pricing gap was observed between these two shipbuilding regions when controlling for vessel characteristics and fuel technology. These findings suggest that while regional cost differences exist, the valuation of green technologies in ship pricing is driven more by vessel attributes and compliance costs rather than shipyard location alone. The results remained robust when the shipyard-fixed and time-fixed effects were controlled, showing that LNG-powered vessels are priced at 30,47%, methanol-powered at 19,00%, and hybrid-powered at 23,86% higher than VLSFO-fueled vessels. The overall cost premium for alternative fuel vessels ranges between 23,12% and 27,76%. The analysis also highlights that while scrubber-fitted vessels running on IFO-380 remain a viable short-term compliance option for sulfur emissions, with a smaller cost premium of 5.65%, alternative fuel vessels are increasingly favoured as a long-term solution to reduce CO_2 emissions. Since alternative fuels such as ammonia do not contain sulfur, they eliminate the need for scrubbers, further influencing fuel choice considerations.

Finally, the study suggests that shipowners investing in alternative fuel vessels are not only responding to regulatory requirements but also strategically positioning their fleets for future market conditions by introducing multiple alternative fuel (hybrid) vessels. Overall, this study contributes to the growing body of research on sustainable shipbuilding, emphasising the financial implications of decarbonisation for shipowners, shipyards, and policymakers in the new building market.

Chapter 6: Investment Strategies in the Container Liner Shipping: Trends, Scenarios, Policy Implications, and Recommendations

This doctoral dissertation has provided a comprehensive examination of investment behaviour in the container liner shipping market. The analysis considered the strategic behaviour of shipowners as the primary stakeholders who operate across three interlinked markets: the second-hand (S&P) market, the time-charter market, and the newbuilding market. The demolition market was explicitly excluded from the scope of this study, due to its different regulatory framework, limited transparency, and operational focus on end-of-life asset management, which diverges from the focus of this research. The central rationale is that shipowners allocate capital not in isolation but by anticipating shifts across these three markets and adjusting their investment behaviour accordingly. By examining these markets individually, this dissertation aimed to explore the way container shipowners can make informed investment decisions in their asset play in the three major operating shipping markets. By integrating decarbonisation targets, market dynamics, and technological advancements, the study aimed to understand the interdependencies between these markets and assess how investment strategies can be considered by shipowners and investors in their asset play. The main research question guided this doctoral dissertation was the following:

"In the context of decarbonisation pressures, how do market dynamics, fuel efficiency, and alternative fuels affect asset values and investment decisions in the container liner shipping industry?"

To address the main research question, Essay 1 explored current market trends and developments in the container liner shipping market and developed three regulatory scenarios to frame the empirical analysis. Building on these insights, Essay 2 to Essay 4 examined the three interrelated markets, each addressing a specific sub-question and collectively contributing to answering the main research question. This final chapter presents the main findings of this doctoral dissertation and interprets the empirical results in light of alternative scenarios. In line with this, Section 6.1 briefly summarizes the research and its main findings. Section 6.2 elaborates on the study's empirical outcomes and provides some considerations for shipowners and investors based on three alternative scenarios as presented in Section 2.5. Section 6.3 provides recommendations for shipowners, investors, and policymakers. Finally, Section 6.4 presents the research limitations, while Section 6.5 provides future research directions.

6.1 Summary of the study and main findings

Starting from the market overview (Essay 1), it was indicated that the global container liner shipping industry has experienced noticeable growth over the past three decades. As of February 2025, container throughput reached approximately 868 million TEUs, with China emerging as the leading contributor to global container trade, with its container throughput increasing from approximately 5 million TEUs in 1996 (representing 3.46% of global trade) to over 250 million TEUs in 2024 (33.76% of the global total), (see Figure 2.1). Furthermore, it was observed that the containership fleet has evolved in both size scale and structure, representing the transition towards larger and more efficient vessels achieved through economies of scale (Figure 2.2). Concerning the fleet age profile, as of February 2025, there were 2,903 vessels under 15 years old (18.45 million TEUs), and 3,257 vessels over 15 years old (9.7 million TEUs), indicating that approximately an additional 10 million TEUs in terms of vessel capacity should be replaced in the following years, especially for vessels do not comply with the IMO and EU regulations (Figure 2.4).

Additionally, the market concentration has intensified, with the top 10 carriers controlling 85.6% of global capacity in 2025, illustrating the increasing concentration and strategic realignment among major market players in the container liner shipping industry (Figure 2.6). The study also revealed a clear divergence in decarbonization strategies among shipowners. To this extent, a central concern is the industry's environmental footprint, particularly its contribution to global GHG emissions. It suggested that containerships are the largest contributors to maritime CO_2 emissions, accounting for approximately 25.4% to 26.7% of total CO_2 emissions output between 2019 and Q3 2023 (Figure 2.18), while in 2024, container CO_2 emissions surged to roughly 244,85 million tonnes of CO_2 (Figure 2.19). As a result, the container shipping industry is facing increasing pressure to reduce its environmental impact and comply with the IMO and EU decarbonisation targets (Essay 2.4.1). These regulatory developments, including measures such as the EEDI, EEXI, CII, and the EU ETS, are reshaping investment behaviour across the container shipping market. As a result, alternative fuel vessels have emerged as a promising transition towards decarbonisation. Nevertheless, it was observed that while some shipowners, like Maersk, CMA CGM, and MSC, are actively contracting vessels with alternative propulsion systems, particularly LNG and methanol, others (e.g. Evergreen, OOCL, etc.) remain concentrated in conventional fuel technologies, reflecting differing risk, regulatory exposures, and technological adoption pathways within the container shipping industry (Figure 2.24). This trend also highlights the investment strategy initiatives of larger companies, which often take the lead in adopting greener technologies, setting a benchmark that smaller firms tend to follow.

In Essay 2, the doctoral dissertation explored the time-charter market and examined whether a vessel's energy efficiency is rewarded in the time-charter contracts. The rationale behind this is that information asymmetry between charterers and shipowners exists as a barrier to the implementation of energy efficiency and technological uptakes of containerships. Empirical estimations suggested that a 1% reduction in the attained Energy Efficiency Design Index ($EEDI_{att}$) leads to a 0.10% to 0.12% increase in daily time-charter rates. The premium was stronger for eco-engine vessels, reaching 0.18% to 0.22% per 1% EEDI improvement, indicating that the charter market increasingly internalises environmental performance, rewarding more fuel-efficient vessels. Additionally, it was indicated that larger, more energy-efficient vessels also secure longer and higher time-charter contracts. These outcomes suggest that shipowners and investors, especially those who invest through the time-charter market, shall continue their actions towards more sustainable practices, as the market already rewards energy efficiency. This can also create competitive advantages, especially for shipowners who embrace technological developments and aim to invest and operate under more sustainable shipping practices.

Continuing in the second-hand (S&P) market (Essay 3), the study investigated whether investment performance can be improved through systematic investment or divestment strategies. The research focuses on small and intermediate containerships, as those vessel sizes are the main candidates in the second-hand market. Using time-series data from 1996 to 2021 for time-charter rates and second-hand prices of small containerships, the study revealed a strong relationship between time-charter rates and second-hand prices, with time-charter rates influencing second-hand prices, providing a strong signal for timing investment or divestment decisions. In addition, due to higher second-hand price volatility, active trading based on technical rules (moving averages, P/E ratios) outperforms passive buy-and-hold strategies for larger vessels (1,700 and 3,500 TEU), while smaller vessels (725 TEU) yield better returns through long-term holding. This suggests that container shipping owners focusing on larger vessels are generally able to align with market economic trends and adjust their investment strategies through active asset play. In contrast, investors primarily investing in small feeder containerships should also consider long-term operational opportunities and adjust their investment strategies not solely based on market timing, but also considering the long-term asset holding and the potential for the vessel retrofit.

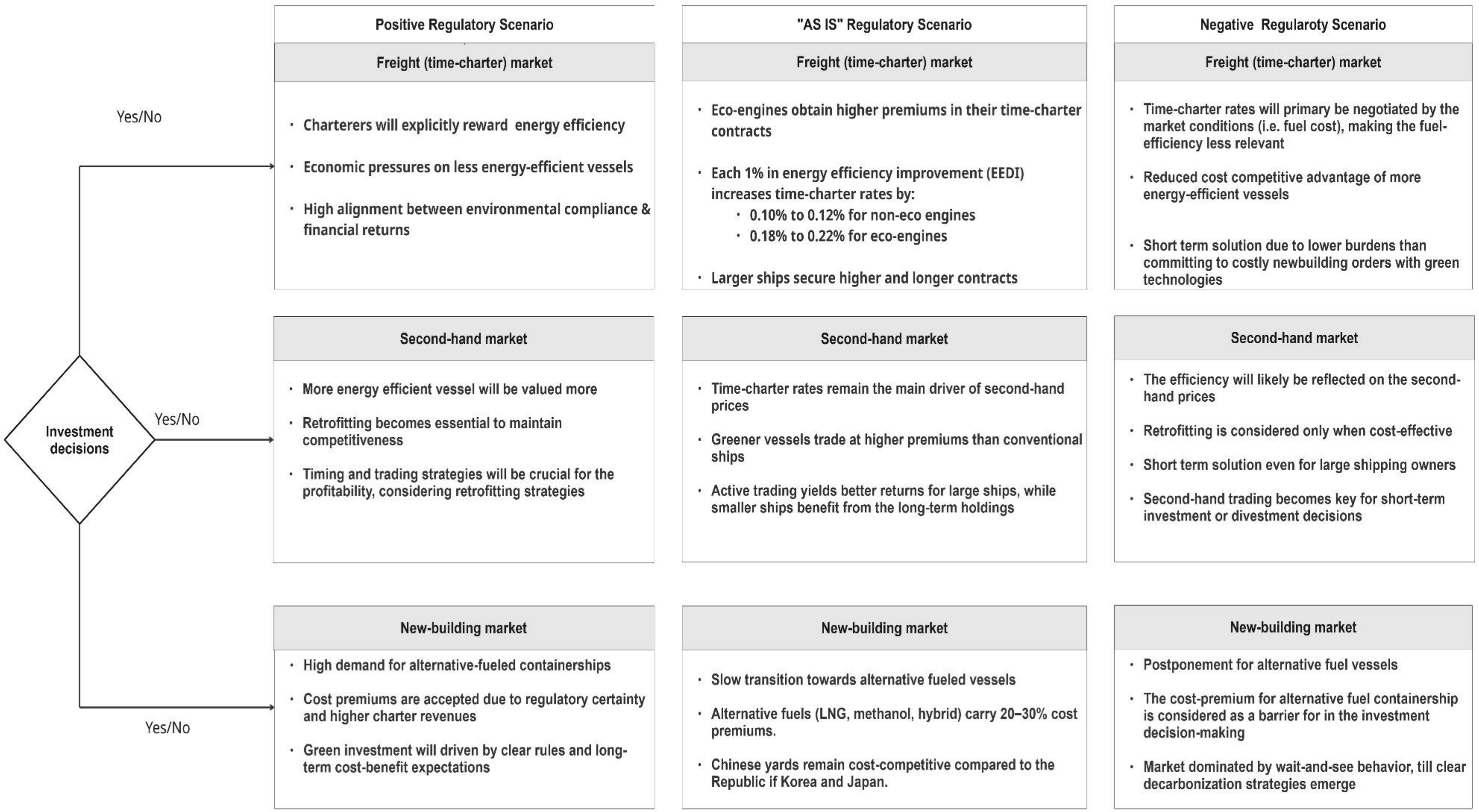
Lastly, in the newbuilding market (Essay 4), based on 1,708 contracts between January 2010 and October 2024, it was indicated that vessels with alternative fuels (LNG, hybrid, methanol) are associated with substantial price premiums of 29.05% for LNG, 23.37% for hybrid, and 18.29% for methanol compared to conventional VLSFO-fueled containerships. Additionally, scrubber-equipped vessels exhibit a smaller premium (~5.55%). These results indicate that green features affect contract pricing, with additional costs linked to technical vessel characteristics, such as gross tonnage (GT) and design speed. Furthermore, regional cost differences persist, with China offering approximately 9.35% lower prices than the

Republic of Korea and Japan, potentially due to China's cost advantages and governmental subsidies. It was also highlighted in Figure 2.23 that bigger containerships, benefiting from economies of scale, were associated with lower unit costs per TEU. LNG was the most expensive option for Feeder Containerships (100 – 2,999 TEUs), while methanol was the most expensive option for very large containerships (over 17,000 TEUs).

6.2 Investment Strategies under Regulatory Scenarios

Drawing insights from the main findings in the previous empirical studies, this part of the discussion brings back the scenario's hypothesis provided in Essay 1, intending to deliver some informative considerations for shipping investors (Figure 6.1). The first scenario ("AS IS" scenario) in the section 2.5.2.1 assumed that IMO and EU decarbonisation measurements will be applied under different time phases. The second scenario ("positive" scenario) in section 6.2.2 assumes strong regulatory algnment between IMO and the EU, with stricter enforcement measures, while the EU carbon allowance prices are assumed to rise even higher, putting a lot of pressure on less energy-efficient vessels. Finally, in section 6.2.3, the third scenario ("negative" scenario), assumes that world trade and technological progress remain stable, but the implementation of IMO and EU measures is only partially effective and remains weak. In all three scenarios, it is assumed that trade growth and technological progress remain constant to isolate the regulatory dimension as the primary driver that affects the investment strategies.

Figure 6.1: Scenario analysis for the investment decisions based on the current market trends



6.2.1 “AS IS” regulatory scenario

Starting with the “AS IS” scenario, IMO and EU measures are expected to be applied under different phases, with carbon prices creating additional costs for conventional vessels. As indicated in Essay 2, current market observations in the time-charter market suggest that more energy efficiency is already embraced by market participants, with a 1% improvement in the Energy Efficiency (EEDIatt) leading to a 0.10% to 0.12% increase in daily time-charter rates. This premium is stronger for eco-engine vessels, reaching 0.18% to 0.22% per 1% EEDIatt improvement, with bigger vessels being associated with higher and longer duration contracts. Vessel size provides an additional advantage, as a 1% increase in gross tonnage (GT) corresponds to a 0.46% increase in time-charter earnings. Contract duration further reinforces this effect, with each 1% longer charter period adding around 0.07% to daily time-charter rates. Therefore, larger and younger vessels are not only associated with higher earnings but also with longer charter durations, as charterers prefer more energy-efficient and bigger vessels. At the same time, the price premium associated with energy-efficient vessels reflects the cost that shipowners must bear when opting to invest in the time-charter market as charterers themselves. To this extent, given the phased transition towards decarbonisation, it is expected that this price premium in the time charter rates will continue to benefit more energy-efficient and bigger containerships. As a result, first movers toward more energy-efficient vessels could benefit from the transition towards decarbonisation, while companies owning less efficient ships will need to update their fleet to remain competitive.

Regarding the second-hand market, empirical results confirm that time-charter rates have a direct impact on vessel second-hand prices, providing valuable signals for the timing of investment or divestment (Essay 3). Larger containerships (e.g. 1,700 TEUs and 3,500 TEUs) exhibit higher second-hand price volatilities, which makes them suitable for trading strategies, while smaller feeder vessels tend to yield higher profits under a buy-and-hold strategy. As the transition towards decarbonisation applies phased measures, shipowners can still consider conventional vessels in the second-hand market as a short-term investment strategy, till stricter regulations make such investments less attractive or technically non-compliant. However, shipowners should steadily align their investment strategies also based on the long-term potentials (i.e. retrofit), especially for the small feeder containerships.

Finally, it is expected that the current order book outlook will steadily present an uptake in alternative fuel vessels, mainly by bigger shipping companies like Maersk, CMA CGM, and MSC. In contrast, smaller companies are likely to continue investing in conventional vessels due to lower capital cost requirements until regulatory requirements and technological adoption become clear. As suggested in Essay 4, shipowners need to consider the additional costs compared to the VLSFO's containerships, with LNG being currently the most expensive option (29,50% more expensive), followed by hybrid containerships (23,27% more expensive), and methanol vessels (18,29% more expensive), while scrubber-equipped vessels command 5,55% higher prices. Additionally, while bigger vessels are benefiting from economies of scale, higher time charter rates, and longer contracting periods, in the new building market, every 1% increase in GT leads to 0.55–0.68% in newbuilding prices, with higher design speeds adding 0.5–0.9% additional cost. This is becoming increasingly important, as potential rerouting or operational speed adjustments will require additional tonnage in the market. At the regional level, Chinese shipyards offer about a 9.4–10% lower prices compared to Japan and the Republic of Korea, creating competitive advantages across the shipbuilding regions. With phased decarbonisation measures, many shipowners may still postpone their orders until regulatory guidelines become clearer or stricter, focusing on either the time-charter or second-hand market, thereby avoiding high capital risks.

6.2.2 "Positive" regulatory scenario

In the "Positive" regulatory scenario, IMO and EU measures are fully aligned and strictly enforced, creating a predictable policy environment and reducing investment uncertainty, while a potential rise in carbon prices will make the less energy-efficient vessel significantly costly.

In the time-charter market, charterers will explicitly reward energy efficiency. As shown in Essay 2, eco-vessels already achieve about 4% higher premiums, while each 1% improvement in EEDIatt leads to a 0.18–0.22% increase in charter rates. Under the positive scenario, these premiums will expand further, creating a significant threat to less energy-efficient ships. Vessel size will continue to provide a competitive advantage, as a 1% increase in gross tonnage results in 0.46% higher daily earnings, and it will also be expected to provide longer contracts. This creates a clear incentive for shipowners to invest in larger and more efficient vessels, as charterers will extensively favour such ships to meet decarbonisation targets.

Regarding the second-hand market, in Essay 3, it was confirmed that time-charter rates are the main driver of second-hand prices, with trading strategies outperforming the buy-and-hold strategy for bigger vessels compared to the smaller containership sizes. In the positive scenario, retrofitting will become essential for competitiveness, particularly for small and medium feeder ships that are otherwise disadvantaged by lower economies of scale. To this extent, shipowners should consider green investments as cost-benefit and as necessary actions for maintaining resale value and meet decarbonisation targets.

Lastly, in the newbuilding market, strong regulation and financial support measures will make alternative fuels the main choice for fleet renewal, with LNG, methanol, and hybrid vessels dominating new orders, despite their price premiums relative to conventional tonnage (Essay 4). Under this positive scenario, these premiums will be widely accepted and considered as investment strategies from a cost-benefit perspective, as shipowners will anticipate higher charter earnings and reduced carbon and regulatory liabilities. Additionally, while vessel size and design speed provide a substantial portion of the total cost, these are offset by economies of scale and the longer-term competitiveness of larger vessels, with Chinese yards maintaining the cost advantage by offering 9–10% lower prices compared to the Republic of Korea and Japan. Overall, in this scenario, shipowners are expected to prioritize green investments, treating decarbonisation targets not as a compliance burden but as a strategic opportunity through a cost-benefit thinking.

6.2.3 “Negative” regulatory scenario

In the negative regulatory scenario, it is assumed that regulatory measurements will remain weak and fragmented, with IMO and EU measures applied inconsistently across regions. Carbon pricing mechanisms will potentially lose credibility, and shipowners will face heightened uncertainty about future compliance requirements. Under these conditions, investment strategies will still rely more on conventional tonnage and short-term solutions.

In the time-charter market, fuel efficiency will potentially become less relevant, as time-charter rates will primarily be negotiated based on fuel costs and market conditions. The eco-premiums observed in Essay 2 will significantly erode, reducing the economic advantages of more energy-efficient vessels. Larger ships will still secure higher earnings due to economies of scale, but the willingness of charterers to pay extra for efficiency will be reduced, making the competitive advantage of eco-vessels weaker. In this context, shipowners will increasingly rely on conventional vessels for short-term chartering rather than committing to costly newbuilding investments.

In the second-hand market, efficiency will only be partially reflected in vessel valuations, and the consistency of any green premium will weaken. Under these conditions, even major shipowners are likely to turn to second-hand acquisitions as a short-term means of securing capacity rather than committing to high-cost newbuilding investments in an uncertain regulatory environment. Larger containerships will remain primarily suited for opportunistic trading strategies, while smaller vessels are expected to deliver comparatively higher returns over the long term. Furthermore, retrofitting will be pursued selectively, only when it proves cost-effective, as owners may prioritize lower capital expenditures

In the newbuilding market, the cost premiums associated with alternative fuels, 29.5% for LNG, 23.3% for hybrid, and 18.3% for methanol vessels (Essay4), will be considered as a cost barrier, especially for less capitalised companies. Shipowners, therefore, will potentially adopt a "wait-and-see" strategy, postponing orders for green vessels until clear decarbonisation measures are clear. Conventional newbuildings will probably continue to be ordered, particularly at Chinese yards, which remain 9–10% cheaper than those in the Republic of Korea and Japan. In this scenario, the absence of strong regulatory support will lead to the postponement of the fleet renewal and the deceleration of decarbonisation, with shipowners shifting primarily toward the second-hand and time-charter markets, with energy efficiency potentially becoming less relevant in the investment decisions.

6.3 Policy Implications and Recommendations

The empirical findings of this research offer several implications for both industry stakeholders and policymakers, particularly in the context of investment decisions, chartering strategies, and regulatory alignment.

First, the analysis confirms that vessel capacity and the adoption of eco-friendly technologies have a significant influence on time-charter rates. This suggests that investments in environmentally efficient vessels can yield substantial revenues, especially under longer charter durations where fuel cost savings and regulatory compliance advantages accumulate over time. Therefore, shipowners and charterers should consider aligning their contractual arrangements to reflect the operational and economic benefits of such vessels.

Second, the study also highlights the importance of long-term collaboration between shipowners and charterers in promoting the adoption of fuel-efficient vessels. While some market participants express a strong preference for energy-efficient tonnage, this preference depends on regulatory compliance and the duration of the contract. Policies that facilitate longer-term charter agreements or provide economic incentives for the deployment of low-emission vessels may therefore prove effective in accelerating fleet decarbonisation. In this regard, regulatory bodies may consider complementary measures, such as green financing mechanisms, differentiated port fees, or emissions-based chartering incentives, to reduce the cost burden associated with greener technologies and promote wider technological uptake.

Third, the second-hand market analysis reveals differentiated investment opportunities based on vessel size and market conditions. For larger containerships (1,700 TEU and 3,500 TEU), which exhibit greater price volatility, active trading strategies may enhance profitability, particularly during market upturns. In contrast, smaller vessels (e.g., 725 TEU) may be better suited to buy-and-hold strategies, except in periods of strong market recovery. Investors are encouraged to employ dynamic valuation frameworks, such as cointegration-based models that track deviations from the long-run equilibrium of the price-to-earnings (p/e) ratio, to better identify entry and exit points in the second-hand market.

Fourth, the observed price premiums for alternative fuel vessels, 29.05% for LNG, 23.37% for hybrid, and 18.29% for methanol containerships, underline the financial challenges associated with decarbonising the fleet. Nonetheless, these vessels represent a strategic long-term investment, not only for regulatory compliance but also for enhancing operational efficiency and securing higher time-charter rates. As such, shipowners are encouraged to prioritise the gradual modernisation of their fleets through the acquisition of low- and zero-emission technologies, particularly in anticipation of tightening global and regional emission standards.

Overall, this analysis suggests that investment strategies should not be based solely on market signals, but rather be informed by decarbonisation measures, with energy efficiency and alternative fuel technologies playing a central role in asset valuation, time-chartering, trading strategies, and ordering decisions.

6.4 Research Limitations

Despite these valuable contributions, this doctoral dissertation also presents opportunities for further research exploration. Concerning the time-charter market, one of the primary limitations pertains to the timeframe, which was constrained by the limited availability of historical data. Even though the data availability permits adequate interpretation of the results, the analysis covers only the period from January 2020 through October 2023. Furthermore, the study excluded the explicit analysis of the relationship between owners and charterers, though such relationships could have a substantial impact on how these preferences are negotiated in the freight (time-charter) market. Additionally, due to data constraints, the analysis did not delve into specific trade lane regions where containerships operate. A more extensive analysis for specific regions or trade lanes could provide better information regarding the operational aspects of the time-charter market and investment decision-making. Moreover, while the IMO and EU continuously introduce measures aimed at decarbonising the sector, this study considered only the attained Energy Efficiency Design Index (EEDI) values as a measure of energy efficiency.

Regarding the second-hand market, the study focused exclusively on three container vessel sizes (725 TEUs, 1,700 TEUs, and 3,500 TEUs), which limits the generalizability of the findings to larger vessel segments. Moreover, time-charter rates were used as a proxy for revenue, omitting the influence of spot market fluctuations, while other macroeconomic variables, vessel specifications, and bargaining power were also excluded from the analysis.

Lastly, in the new-building market, to maintain simplicity, the analysis excluded additional explanatory variables such as macroeconomic factors, including steel prices, interest rates, global trade volumes, and fuel price volatility. Secondly, factors such as shipowners' negotiation power, market expectations, and second-hand vessel prices, though potentially impacting newbuilding prices, were not considered in the analysis. Similarly, shipowner preferences and strategic motivations (e.g., long-term operational costs, market positioning, and operational routes) were not explicitly modelled in the investment decision processes. Thirdly, while the analysis captured vessel specifications and fuel types, it did not evaluate the long-term operational performance and cost-effectiveness of alternative fuel vessels, which could influence future investment behaviour.

6.5 Future Research

This study provides a foundation for several future research directions related to the newbuilding, time-charter, and second-hand container markets, particularly under the influence of ongoing decarbonisation pressures and regulatory changes.

Regarding the freight market, future research should explore the long-term implications of current decarbonisation trends, particularly the heterogeneous impact of charterers' preferences for emission reduction, the duration of cooperation between shipowners and charterers, and the evolving regulatory requirements. Longer time series for analysis would enable a more robust understanding of how key variables influence time-charter rates over different market cycles. As alternative fuel-capable vessels, such as those running on LNG, biofuels, or ammonia, continue to enter the market, future studies should investigate how operating under these fuels affects time-charter performance, route deployment, and profitability. Furthermore, it is important to explore how the interaction between vessel characteristics and chartering strategies influences shipowner–charterer relations. These dynamics may vary significantly depending on vessel size, submarket, and geographical context. Future analysis should therefore include a broader range of vessel types and regions, with particular attention to how preferences for efficiency and sustainability are negotiated in practice across different market segments.

In the second-hand market, future studies could apply the current methodological approach to larger containerships, where higher capital values and greater volatility present new challenges and opportunities for investors. The inclusion of spot rates, in addition to time-charter rates, would enhance the analysis of short-term market dynamics and earnings potential. Moreover, this framework could be extended beyond container shipping to other vessel types, such as Ro-Ro ships and LNG carriers, to assess how green investments impact asset valuation across decarbonising sectors. Another avenue for research concerns a more detailed examination of the price-to-earnings (p/e) ratio, particularly how deviations from long-run equilibrium can be interpreted to inform trading strategies. Analysing how green investment decisions affect both charter rates and second-hand valuations may also provide useful insights for aligning newbuilding and resale strategies. Future research should continue to evaluate how macroeconomic developments, government incentives, and geopolitical risks shape investment behavior in second-hand vessels and influence the broader transition toward a more sustainable maritime industry.

In the context of the newbuilding market, future research should examine how macroeconomic variables, such as interest rates, steel prices, fuel price volatility, global trade patterns, and shipyard capabilities, shape shipowners' investment decisions. These broader economic indicators play a significant role in determining the timing, type, price, and scale of new orders. Further investigation into how green investments influence both time-charter rates and second-hand market valuations could also provide important insights for shaping newbuilding strategies. While China continues to hold a cost advantage in vessel production, the Republic of Korea and Japan remain focused on high-tech and specialised shipbuilding. A deeper analysis of regional competitiveness, production efficiencies, and the role of government support measures, such as subsidies or state-backed financing, would offer valuable guidance for shipyards navigating the transition to low-carbon technologies. Additionally, geopolitical developments require closer scrutiny. The potential return of protectionist policies, for instance, under a second Trump administration, could reshape the global shipbuilding landscape. Renewed efforts to strengthen domestic ship production in the United States and reduce reliance on Asian shipyards may have implications for both market competitiveness and investment decisions. Understanding how such geopolitical shifts influence investment in sustainable ship technologies is critical for anticipating strategic responses across the maritime industry.

Future research should also consider the role of the learning curve in the adoption of green technologies. As more alternative fuel-capable vessels are built and shipyards and suppliers gain experience, costs are expected to decline over time. Future studies should therefore investigate how learning effects differ across technologies such as LNG, methanol, or ammonia, and how these dynamics shape shipowners' willingness to order new vessels. Linking the learning curve with policy incentives, such as subsidies or carbon pricing, could offer a better understanding of when alternative fuels may become cost-competitive in the newbuilding market.

In parallel, retrofitting strategies should be assessed as a complementary pathway to fleet renewal. Investigating the economic viability, technical challenges, and policy incentives for retrofitting existing vessels with dual-fuel engines, fuel cells, or carbon capture systems would provide valuable insights into how shipowners can balance compliance, cost, and competitiveness without fully committing to newbuilding investments.

Finally, as the demolition market was explicitly excluded from the scope of this study, due to its different regulatory framework, limited transparency, and operational focus on end-of-life asset management, which diverges from the focus of this study, future research should examine how scrapping decisions interact with green investment strategies and regulatory pressures. As older, less efficient vessels become economically and environmentally less attractive, demolition trends may accelerate, especially under tightened emissions regulations or in periods of low freight rates. Understanding the timing and drivers of scrapping decisions, as well as the role of carbon pricing, recycling capacity, and international safety and environmental standards (e.g., the Hong Kong Convention), is crucial for modelling fleet renewal dynamics. Future studies could also explore how demolition activity affects second-hand vessel prices and newbuilding demand, thereby closing the loop in fleet evolution under decarbonisation pathways.

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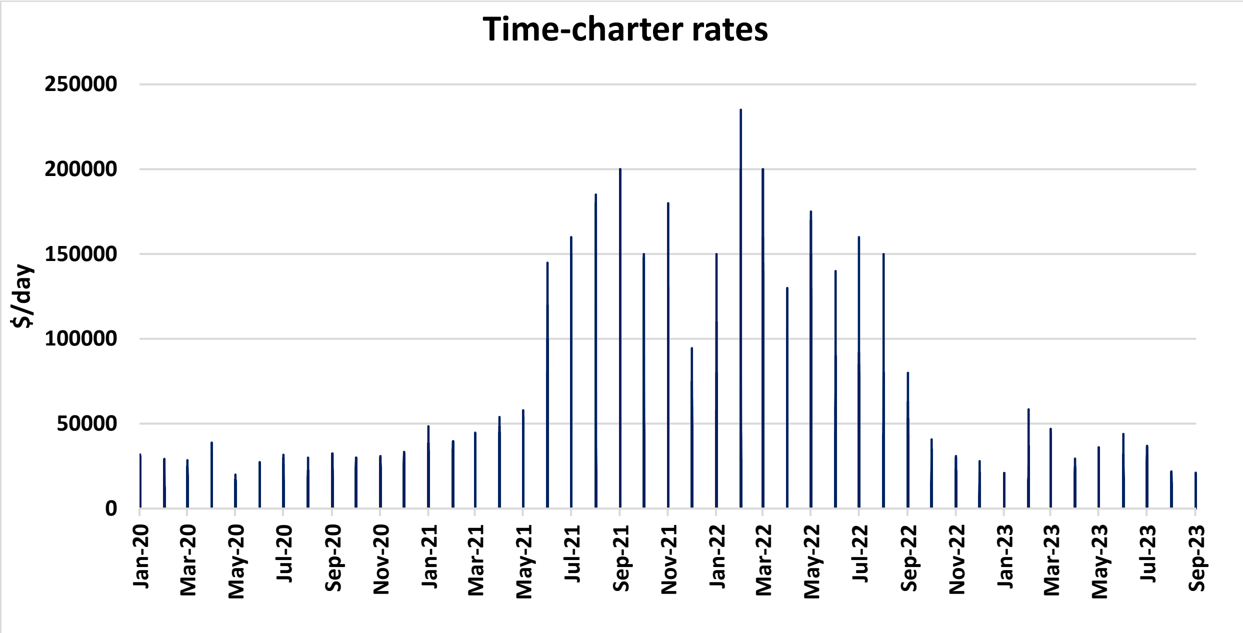
Appendix A - Aggregate charter rates over January 2020 - October 2023

Appendix A -Aggregate charter rates over January 2020 - October 2023



Appendix B - Variance Inflation Factors from Table 3-2

Centered VIF				
Eco - Engines			**Non - Eco - Engines**	
Macro Variable	**Regression model 1**	**Regression model 2**	**Regression model 1**	**Regression**
ln(PMI)	2.041	2.274	2.072	2.347
ln(Fuel_Price)	2.962	6.019	3.351	6.127
ln(Charter_Period)	3.137	3.366	2.497	2.830
ln(IDLE)	2.853	3,578	3.008	3.383
Micro Variables				
ln(TEU)	2.967	2.374	1.900	1.902
ln(EEDI)	2.606	2.168	1.303	1.340
ln(AGE)	1.476	1.434	1.195	1.273
Dummy-Pre-COVID-19		3.806		3.787
Dummy-Market boom and recession		2.368		2.147

Appendix C - Variance Inflation Factors from Table 3-3

Centered VIF				
Eco - Engines			**Non - Eco - Engines**	
Macro Variable	**Regression model 1**	**Regression model 2**	**Regression model 1**	**Regression**
ln(PMI)	2.041	2.274	2.072	2.347
ln(Fuel_Price)	2.962	6.019	3.351	6.127
ln(Charter_Period)	3.137	3.366	2.497	2.830
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ln(AGE)	1.476	1.434	1.195	1.273
Dummy-Pre-COVID-19		3.806		3.787
Dummy-Market boom and recession		2.368		2.147

Appendix D - Coefficient transformation from Table 5-2

$(e\beta-1)\times 100$								
	Model 2		Model 3		Model 4		Model 5	
Dummy Variable	Coefficient (β)	Premium /Discount (%)	Coefficient (β)	Premium /Discount (%)	Coefficient (β)	Premium /Discount (%)	Coefficient (β)	Premium /Discount (%)
Dchina	-0,124	-11,66%	-0,098	-9,34%	-0,094	-8,97%	-0,099	-9,43%
Dkorea	-0,080	-7,68%	-0,004	-0,40%	0,006	0,60%	0,002	0,20%
ALT_FUEL			0,201	22,26%	0,235	26,49%		
Scrubbers					0,053	5,44%	0,054	5,55%
LNG							0,255	29,05%
Methanol							0,168	18,29%
Hybrid							0,210	23,37%

Appendix E - Variance inflation factors from Table 5-3

	model 1		model 2		model 3		model 4		model 5	
Variables	Coeff.	Cent. VIF	Coeff.	Centerd VIF	Coeff.	Centerd VIF	Coeff.	Centerd VIF	Coeff.	Centerd VIF
LN_GT	0,677	2,911	0,628	10,254	0,606	13,996		14,919	0,599	14,714
LN_SPEED	0,510	2,911	1,000	9,260	0,961	8,631		8,387	0,931	8,416
DCHINA			-0,125	2,614	-0,098	2,165		2,057	-0,094	2,158
DJAPAN			-0,081	2,101	-0,005	1,736		1,762	0,006	1,915
Alt_Fuels					0,201	5,562		8,035		
IFO_380								3,209	0,054	4,996
LNG									0,255	6,555
METHANOL									0,169	2,162
HYBRID									0,210	3,495
D2011			0,045	3,723	0,053	3,124		3,268	0,048	2,494
D2012			0,041	1,461	0,013	1,335		1,359	0,008	1,518
D2013			0,013	1,883	0,001	1,960		2,279	-0,009	2,661
D2014			0,113	2,087	0,059	1,806		1,862	0,052	2,329
D2015			0,100	4,304	0,053	3,095		3,292	0,051	5,041
D2016			-0,156	1,378	-0,232	1,347		1,345	-0,244	1,096
D2017			0,090	2,668	-0,065	1,718		1,694	-0,081	2,218

D2018			0,029	2,473	-0,047	3,493		3,569	-0,062	3,746
D2019			0,113	2,416	0,085	3,741		3,421	0,057	5,497
D2020			0,095	2,349	0,010	2,058		2,073	-0,001	2,536
D2021			0,293	2,883	0,201	2,851		3,045	0,190	2,821
D2022			0,587	2,238	0,438	2,125		2,252	0,434	2,732
D2023			0,718	2,541	0,550	2,299		2,313	0,571	2,792
D2024			0,741	1,303	0,626	1,250		1,258	0,613	2,929
Average VIF		**2,911**		**3,219**		**3,384**		**3,570**		**3,855**

Appendix F - Coefficient transformation from Table 5.4

(eβ−1)×100						
	Model 3		Model 4		Model 5	
Dummy Variable	Coefficient (β)	Premium / Discount (%)	Coefficient (β)	Premium / Discount (%)	Coefficient (β)	Premium / Discount (%)
Alternative Fuel	0,208	23,12%	0,245	27,76%		
IFO-380			0,055	5,65%	0,055	5,65%
LNG					0,266	30,47%
Methanol					0,174	19,00%
Hybrid					0,214	23,86%

Appendix G-Coefficients and Variance Inflation factors from Table 5.4

	model 1		model 2		model 3		model 4		model 5	
	Coeff.	Centerd VIF	Coeff.	Centerd VIF	Coeff.	Centerd VIF	Coeff.	Centerd VIF	Coeff.	Centerd VIF
LN_GT	0,677	2,838	0,595	6,066	0,557	6,822	0,548	7,365	0,550	7,711
LN_SPEED	0,513	2,838	0,671	2,802	0,654	2,639	0,617	2,269	0,619	2,295
Alt_Fuels					0,208	5,697	0,245	9,360		
IFO_380							0,055	4,931	0,055	4,996
LNG									0,266	6,555
METHANOL									0,174	2,162
HYBRID									0,214	3,495
D2011			0,049	1,984	0,074	2,926	0,071	2,611	0,069	2,494
D2012			0,017	1,664	0,014	1,516	0,008	1,549	0,008	1,518
D2013			-0,001	1,689	0,006	1,955	-0,001	2,700	-0,002	2,661
D2014			0,119	2,559	0,070	2,205	0,070	2,353	0,065	2,329
D2015			0,094	7,389	0,064	4,059	0,066	5,228	0,060	5,041
D2016			-0,066	1,166	-0,110	1,075	-0,109	1,084	-0,107	1,096
D2017			0,090	6,015	-0,046	2,132	-0,042	2,183	-0,062	2,218
D2018			0,059	3,283	-0,026	3,818	-0,030	4,023	-0,040	3,746
D2019			0,113	5,759	0,124	6,055	0,106	5,717	0,106	5,497

D2020			0,114	2,668	0,030	2,180	0,026	2,747	0,015	2,536
D2021			0,296	3,070	0,214	2,890	0,207	2,821	0,202	2,821
D2022			0,593	2,697	0,466	2,449	0,457	2,607	0,463	2,732
D2023			0,726	2,290	0,549	3,172	0,541	2,791	0,575	2,792
D2024)			0,707	2,920	0,612	2,118	0,603	2,700	0,596	2,929
Average		2,838		3,376		3,159		3,613		3,381