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Carbon Capturing Systems in the maritime industry: A sustainable business model to complement the net-zero transition

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ABSTRACT: This thesis examines the economic and environmental benefits of implementing carbon capture and storage (CCS) systems on commercial cargo ships. It focuses on Europe, the USA, and China, analysing environmental impact and financial viability. Using Net Present Value (NPV) analysis and data from empirical studies, the research incorporates credit forecasting to assess future carbon credit prices. The findings show Europe to be the most financially viable, while the USA and China face economic challenges. All regions, however, show significant CO2 emission reductions. The study emphasizes the need for technological innovation, supportive policies, and strategic financial planning to enhance CCS adoption in the maritime sector, aiding global emission reduction targets and industry sustainability.

Keywords: Carbon Capturing and Storage, Carbon Credits, CO2 emissions.

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CHAPTER 1 Introduction

In response to rising environmental concerns, over 140 member countries of the United Nations have committed to achieving net-zero emissions by 2050 (United Nations, n.d.). This global commitment has led to increased sustainability regulations for various industries, including the maritime sector, which accounts for more than 2.1% of global greenhouse emissions (Baldi et al., 2014). The shipping industry in particular faces significant pressure to reduce its carbon footprint. Al-Enazi et al. (2021) highlight that stringent environmental regulations will drive a shift towards carbon-neutral fuels such as methanol, ammonia, and hydrogen. Investments in vessels powered by these alternative fuels, like Maersk's methanol-powered ship *Ane Mærsk*, indicate the industry's commitment to sustainable practices. However, these fuels are not yet competitive with traditional bunker fuels due to higher market prices and storage and maintenance costs (Notteboom & Vernimmen, 2009).

The substantial expenses associated with bunker fuels and the uncertainty surrounding the most efficient alternative fuels present significant risks for shipping companies. Achieving sustainability goals while maintaining profitability remains a formidable challenge. In this context, Carbon Capture and Storage (CCS) systems offer a promising solution. CCS technologies capture emissions from ships and store them, providing dual revenue streams through the sale of carbon credits and captured CO2 (Anderson & Newell, 2004). Although CCS has the potential to facilitate the transition to net-zero emissions by 2050 (Page et al., 2020), its economic benefits for the shipping industry require further investigation. Therefore, this thesis aims to address the following research question:

What are the economic benefits of implementing onboard post-combustion carbon capture and storage systems on commercial cargo ships?

Two hypotheses are formulated:

H_1: Implementing CCS systems in the maritime industry leads to positive financial outcomes.

H_2: Implementing CCS systems in the maritime industry leads to substantial reduction in CO2 emissions

To answer the research question, several key aspects will be explored:

1. **Environmental Impact**: Forecasting the amount of carbon emissions by commercial ships and calculating the reduction in CO2 emissions achieved through post-combustion CCS systems.

2. **Financial Analysis**: Analysing future CO_2 emissions and market price trends for captured CO_2 and carbon credits by 2050. By comparing future cash flows from emission reductions to operational costs, the financial benefits of CCS systems in the shipping industry will be assessed.
3. **Technological Overview**: Providing a brief explanation on the commercial use of various post-combustion carbon capture technologies.

The analysis will focus on the economic benefits of implementing CCS systems in three key regions: Europe, the USA, and China. These regions have been selected due to their significant share of global maritime activity and distinct carbon allowance systems. The European Union Emissions Trading System (EU ETS) is one of the most established and comprehensive carbon trading systems globally, covering a broad range of industries, including maritime transport. The California Carbon Allowances (CCA) system reflects California's progressive environmental policies and innovative approaches to carbon management. As one of the largest economies in the USA, California's carbon trading system provides a significant case study for understanding the economic impacts of CCS in a dynamic region. China, as the largest emitter of CO_2, has recently established its national carbon market. Studying the Chinese Emission Allowances (CEA) system provides insights into the challenges and opportunities in an emerging carbon trading market, with China's vast shipping industry and rapid economic growth making it a critical region for analysing the scalability and economic benefits of CCS technologies. Understanding these three systems is essential for assessing global strategies to reduce emissions, given their significant roles in global trade and emissions.

Data for this analysis will be sourced from empirical studies on CCS system efficiency, the United Nations Conference on Trade and Development (UNCTAD) for fleet composition and emissions data, and historical trading prices for carbon credits and liquid CO_2. Time series analyses, utilizing Exponential Smoothing prediction model, will forecast trends in CO_2 emissions and carbon credit markets, ensuring robust predictions through statistical error measures and scenario analysis.

The economic feasibility of CCS systems will be evaluated using analysis, incorporating projected revenue streams from carbon credits and captured CO_2 sales against operational and installation costs. This comprehensive approach aims to provide a detailed assessment of the potential economic benefits of CCS systems for the maritime industry in Europe, the USA, and China, contributing valuable insights towards achieving global emission reduction targets and ensuring the industry's long-term sustainability.

CHAPTER 2 Literature review

2.1 Context of CCS in Shipping

According to the European Commission, the shipping industry accounts for roughly 3% of global carbon emissions, and this percentage could jump up to 10-13% if no action is taken (King, 2022). The primary source of these emissions is the exhaust gases from fossil fuel engines, which is still the preferred mode of propulsion. OECDstatistics (2023) estimates that the total CO2 emissions by the global fleet are around 858 million tonnes (). The International Maritime Organization (IMO) has set the goal of reducing CO2 emissions by 20-30% by 2030, and 70-80% by 2040, compared to 2008 levels (IMO, 2023).

The growing stringency in regulations pushes firms to seek alternatives and invest in R&D. This is also the main reason why Al-Enazi et al. (2021) suggest that a shift towards carbon-neutral fuels such as ammonia, methanol, and hydrogen is inevitable. Fuels are a significant part of the operational expenses of shipping lines (Notteboom & Vernimmen, 2009), which implies that for this transition to happen, alternative fuels must be cost-competitive.

Currently, the preferred power source in the shipping industry is diesel, also known as bunker oil (Serra & Pancello, 2020). Serra & Pancello (2020) state that "around 95% of the global fleet is reported to run on diesel". The preference for bunker oil lies in its affordability compared to alternatives. However, its quality is low, resulting in high emissions per power output, even when the most advanced marine engines are utilized (Serra & Pancello, 2020).

While the transition to alternative fuels seems inevitable, it is evident that the technology to make this transition without causing severe economic damage to the shipping industry has not yet been developed. The obstacles to commercial use of alternative fuels make the usage of other technologies for reducing emissions a necessity in the net-zero transition. Carbon Capturing and Storage (CCS) systems are among these technologies. Tavakoli et al. (2024) discuss the technical details of integrating CCS into ship designs. The integration of CCS on ships primarily involves the inclusion of an absorber and a regenerator (or stripper). The absorber captures CO2 from the ship's exhaust gases using a solvent, typically an amine-based solution. The regenerator then heats the solvent to release the captured CO2 in a concentrated liquid form, which can then be compressed and stored in tanks for CO2.

The captured CO2 can be used in several ways in different industries. According to Lloyds (2022), captured CO2 is utilized primarily for enhanced oil recovery (EOR) and geological storage. In the EOR process, CO2 is injected into oil fields to increase crude oil extraction, simultaneously storing the CO2 as it displaces oil and water in the reservoir. Geological storage involves compressing and transporting captured CO_2 to deep underground rock formations, such as saline formations and depleted oil and gas reservoirs, for permanent sequestration. Additionally, captured CO_2 supports decarbonization and the production of low-carbon fuels like blue hydrogen, which is crucial for decarbonizing industries such as steel, cement, and petrochemicals.

Several methods for carbon capturing can be utilized, with the three most developed being post-combustion, pre-combustion, and oxy-fuel (Dziejarski, Krzyżyńska, & Andersson, 2023). In pre-combustion capture, fossil fuels are partially oxidized and reacted with steam to produce syngas (CO and H_2O), which is further converted to CO_2 and H_2. The CO_2 is captured before combustion, with operating conditions at 20–30 bar pressure and high temperatures (Chao, Deng, Dewil, Baeyens, & Fan, 2021). Oxy-fuel combustion burns fuel in oxygen instead of air, producing flue gas mainly composed of CO_2 and impurities like SO_x, making it suitable for CCS storage without separating CO_2 from N_2. However, the high oxygen concentration changes ash chemistry, leading to issues such as corrosion, fouling, potential leaks, high maintenance costs, and stringent safety management, which decreases net efficiency and increases fuel consumption due to the required power for oxygen separation and CO_2 purification (Chao, Deng, Dewil, Baeyens, & Fan, 2021).

Out of the above-mentioned methods of carbon capturing, post-combustion carbon capture is particularly suitable for commercial applications due to its technological maturity and adaptability for integration with existing infrastructures. This method primarily utilizes absorption-based techniques, where chemical solvents like amines efficiently capture CO_2 from flue gases. Such systems can be retrofitted to power plants and other industrial settings, offering a pragmatic solution for reducing greenhouse gas emissions without significant modifications to existing operations (Salah et al., 2023).

The study "Exploring the technical feasibility of carbon capture onboard ships" (Tavakoli et al., 2024) assesses the practicality of implementing carbon capture systems (CCS) on ships, both retrofitted and newly built. It concludes that achieving up to 90% CO_2 reduction is feasible with current technology. The biggest challenges identified with the use of this type of CCS systems are space constraints, increased energy consumption (70%-100% higher for new builds), and economic factors. Despite the high operational costs, the use of CCS could be economically viable if alternative fuel prices remain high (Tavakoli et al., 2024).

2.2 Costs of CCS systems

There are few estimations and a limited amount of research published on the economic and environmental impacts of the application of CCS on the maritime industry. The available information on Capital Expenditure and Operational costs is mostly from case studies, using different types of vessels. Luo and Wang (2017) examine solvent-based carbon capture technology model for a cargo ship with total power of 17MW and estimate a cost of 77.50 €/ton CO2 for 73% percent capture rate, and 163.07 €/ton CO2 for 90% capture rate. Feenstra et. al (2019), analysed the feasibility of a post-combustion CCS technology on a LNG-fueled ship with 3000kW engine. They estimate an optimal operational cost of 98$/ton-CO2 for 90% capture rate and CAPEX at $660/kWh. The same CAPEX proportion is used as reference by Zincir et al. (2024) to evaluate the environmental and economic performance of a post-combustion solvent-based carbon capture system on a 48,600 kW engine container ship to meet the International Maritime Organization's emission reduction strategies through 2050. Furthermore, in a recent study conducted by Güler and Ergin (2021), operational expenditures decreased to $57.79 per ton of CO2 at 90% capture rate, which showcases that operational costs keep decreasing due to technological innovation and optimization. Moreover, in this study required MEA solvent is estimated to be 1.696 kg per ton of captured CO2.

2.3. Modelling and Analysis Approach

2.3.1 Forecasting Model

To make predictions about the future prices of Carbon Credits and the Amount of CO2 emitted by the shipping industry, an Exponential Smoothing (ETS) forecasting method is utilized. Exponential Smoothing models are widely used for forecasting in business (Gardner, 1958) and show good predictive performance compared to other more sophisticated approaches (Makridakis & Hidon, 2000). The origins of exponential smoothing trace back to Robert Brown's development of a tracking model for fire control information (Gass and Harris, 2000). In 1957, Charles Holt developed a similar forecasting method. (Holt 2004). Winters (1960) later applied Holt's method to provide empirical evidence, leading to the widespread adoption of what became known as the Holt-Winters forecasting method. Subsequent variations of this method, designed to address seasonality effects, have all been extensions of Winters' original approach . Simple Exponential Smoothing is utilized by Fatima et. al (2019) to predict Carbon Emissions in Asian countries and is found to have high predictive power. A research study conducted by Choi et al. (2014) has used a double exponential smoothing model for estimating the trend in CO2 emission for the US transportation sector. Zhu et al., (2019) use an altered version on Holt's Exponential Smoothing model to forecast carbon prices in China.

2.3.2. Economic Modelling

As of now, there is no academic work which aims to examine the implementation of CCS systems in terms of monetary value in the maritime sector specifically. Several studies have utilized cost-benefit analysis (CBA) to evaluate the economic viability of CCS systems in various industries. Cost-benefit analysis involves comparing the costs of implementing CCS technology with the anticipated economic benefits, such as reduced carbon emissions penalties and potential savings from carbon credits. Fan et al. (2020a) conducted a cost-benefit analysis of CCS retrofitted to different types of thermal power plants in China. The researchers used a trinomial tree model based on a real options approach to evaluate the investment decisions, incorporating various uncertainty factors such as carbon price, technological progress, and government subsidies. Leeson et al. (2017) conducted a techno-economic analysis on CCS applied to iron and steel, cement, and oil refining industries, studying the total costs and mitigated emissions by 2050. They incorporated a learning curve factor in their model to account for reduction in operational expenditures due to technological progress.

To evaluate the financial performance of implementing CCS on ships, an NPV analysis was utilized. NPV analysis discounts future cash flows to present value to assess the profitability of an investment. For long-term projects like CCS, this method is crucial to evaluate the economic viability by comparing the initial and operational costs against the long-term benefits over the life-cycle of the project. Cucchiella et al. (2014) use this analysis method to evaluate the profitability small, medium, and large investments the renewable energy sector. In their research, Fan et al. (2020a) calculate the NPV to evaluate the value of the project studied in their case. However, this approach does not account for the potential value of uncertainty factors (Fan et al., 2020b).

2.4 Justification for Closed-loop Systems

Open-loop scrubbing systems, while cost-effective, pose significant environmental risks due to untreated discharge into the sea. Closed-loop systems, which recirculate and treat the water onboard, present a more sustainable option. Dulière, Baetens, and Lacroix (2020) highlight the potential pH decrease in marine environments due to open-loop systems, stressing the need for regulatory measures. Therefore, focusing on closed-loop CCS systems aligns with both environmental sustainability and anticipated regulatory trends.

Scrubbing can be open-loop, closed-loop, or hybrid. Open-loop systems intake seawater, spray it into the exhaust, and discharge it back into the sea, often without treatment. Closed-loop systems use a tank of freshwater mixed with alkaline substances onboard. This water is sprayed into the exhaust, filtered to remove solid particles, and then recirculated, with a small amount of "bleed-off" water discharged. Hybrid scrubbers can operate in either open-loop or closed-loop mode (Boxcar-Admin, 2021). Around 80% of scrubbers installed are with open-loop systems, which are associated with significantly lower installation and operating costs, but also with environmental pollution (Boxcar-Admin, 2021). Dulière, Baetens, and Lacroix (2020) estimate that if 15% to 35% of the fleet (by gross tonnage) operating in the English Channel and the southern North Sea were equipped with open-loop or hybrid scrubbers, the annual pH decrease would range from 0.004 to 0.010 pH units. This is comparable to the ocean's acidification over two to four years due to climate change. Near Rotterdam, the pH drop could reach up to 0.088 pH units per year, a change that would typically occur over 30 to 50 years due to climate change (Dulière, Baetens, & Lacroix, 2020). This creates a greenwashing problem and suggests that there might be legal restrictions introduced by the government in the future regarding the usage of this scrubbing system. Therefore, the study will focus on the implementation of closed-loop CCS systems.

CHAPTER 3 Methodology

3.1 Technological progress model

To account for the costs reductions due to technological progress, a similar model from the study on the total global costs of CCs implementation in industry of Leeson et al. (2017) was adopted. This method simulates the learning curve based on technology penetration variable *tp* to account for the decrease in operational expenditures.

Technology penetration

Technology penetration *tp(y)* represents the fraction of plants in an industry that has CCS technology applied in a given year *y*. S-shaped curve is used to represent how the adoption of CCS technology starts slowly, accelerates, and then slows down as it reaches maximum penetration. Here, a maximum penetration of 100% in 2050 is assumed. The start year of first implementation *SD* is 2025, and an arbitrary constant *U* representing the uptake rate is assumed to be 3. The equation is represented in Eq. (1).

$$tp(y) = exp\left(-\left(\left(U - U\left(\frac{y-SD}{2050-SD}\right)\right)^2\right)\right) \times tp_{\max} \tag{1}$$

Therefore, the total number of ships with CCS applied to them *n(y)*, within any year *y* can be found by multiplying the maximum number of vessels n_{max} by *tp(y)*. (see Eq.2)

$$n(y) = tp(y) \times n_{max} \tag{2}$$

Learning curve

The learning curve factor *lc(y)* represents the cost reduction associated with the development of the technology. The cost of CCS technology decreases as more vessels adopt it, thanks to technological improvements and learning effects. This reduction is modelled to occur every five years, starting once a certain penetration threshold is reached. The cost reduction per generation *CR* is assumed to be 7%, with the minimum threshold cost reduction threshold CR_{min} being 5%. The learning curve factor can be formulated as follows (Eq. 3):

$$lc(y) = \begin{cases} (1-CR) \times lc(y-1) & \text{if } tp(y) > CR_{min} \\ lc(y-5) & \text{otherwise} \end{cases} \tag{3}$$

Escalated operational costs

The escalated cost *ec(y)* represents the operational costs for the given year and is measured in euros per tonne of CO2 captured. It accounts for the initial operational cost for CO2 capturing *P*, adjusted to learning curve effects *lc(y)* and inflation *i* over time. *P* is taken from the literature and is measured in euros per tonne of CO2 captured (€/tCO2). Its value is taken from literature and is assumed to be $57.79 per ton of CO2 as of the most recent study, which is equivalent to €52.93 per ton of CO2 as of August 2024 exchange rates (European Central Bank,2024). The inflation rate *i* is taken from the median inflation rate for the Euro Area from the period between 2000 to 2022, which is equal to 2.2% (European Central Bank, 2024). *S* denotes the captured emissions per vessel. Equation 4 and 5 represent the formula for the escalated operational costs and the total operational costs for a given year *y*, respectively.

$$ec(y)=P\times lc(y)\times i \tag{4}$$

$$c(y)= n(y)\times S\times ec(y)) \tag{5}$$

In addition to the operational costs, costs for the solvent will be incorporated. The required MEA solvent will be taken from the case study conducted by Güler and Ergin (2021), which is stated to be 1.696 kg per ton of captured CO2. For the simplicity of the analysis, it will be assumed that the solvent will not acquire any other expenses other than that of purchasing it.

3.2 Computation of Capital Expenditure for CCS systems

As of now, there is no defined purchasing price for Carbon Capturing and Storage systems. Therefore, the Capital Expenditure price for CCS systems will be computed by taking the proportion between the construction cost and propulsion power of the engine, as it has been done in previous studies, such as that of Zincir et al., (2024). The proportion used will be $660/kW, derived from literature, which is equal to €603.79/kW as of August 2024 exchange rates. The life of a CCS system is assumed to be 26 year, or the studied period for the forecast analysis.

However, the problem about computing CAPEX for each vessel arises. As there is no detailed information about the propulsion power of each of the vessels used, the strong assumption that each fleet in the studied regions consists of homogeneous ships must be established. Moreover, for the simplicity of the analysis, it will be assumed that the maritime fleet composition and number of vessels stays constant. To construct the case ship, the total mass in Dead-Weight Tons (DWT) will be averaged based on total number of ships. Then, based on information of case studies, the power of the propulsion system will be derived, assuming that DWT and engine power are correlated. The propulsion power will be computed using linear regression, with propulsion power *PP*, measured in kW, being the dependent variable and the deadweight of the vessels *DWT* being the independent variable. (see Eq. 6)

$$PP=A + m \times DWT \tag{6}$$

Where *A* is the intercept and *m* is the slope. After performing a linear regression analysis, the resulting linear relationship is described by Equation 7. For more details about the computation and data used, see Appendix 1.

$$PP=8023 + 0.3168 \times DWT \tag{7}$$

Moreover, to account for the increase in the initial cost of implementing CCS systems throughout the years, the Material Index for Steel Vessel Contracts *vi* will be utilized. The median index for the period between 2010 to 2019 will be used. The total Capital Expenditures CAPEX for the period *y* are:

$$CAPEX(y) = PP \times 603.79 \times (1+vi)^{y} \times (n(y)-n(y-1)) \tag{8}$$

However, in this model gradual implementation of CCS systems through the studied period is assumed. As the economic evaluation is done through NPV analysis, this implies that problems with the evaluation of Cash Flows may arise if the entire CAPEX costs are borne at the moment of installing the system. This is due to the fact that if a CCS system is installed towards the end of the studied period (e.g. 2045), a massive cash outflow will occur without taking into consideration the cash inflows beyond 2050. Therefore, the CAPEX for installation will be divided in 26 payments to aggregate for the life of the project. Similar aggregation has been done in previous studies (Leenstra et al., 2017). A new variable *CapY(y)* reflecting the total payment done for year *y* is created by the following computation:

$$CapY(y) = \frac{1}{26}PP \times 603.79 \times (1+vi)^{n} \times n(y) \tag{9}$$

3.3 Net Present Value Analysis

In the maritime industry, assessing the profitability of investments commonly involves the use of (NPV) and Internal Rate of Return (IRR). These methods are extensively utilized by ship operators and maritime project managers, often in conjunction with various sensitivity analyses. Just as interest rates reflect the time value of money, future payments are considered less valuable than immediate payments. The NPV method, also known as the annuity method, enables the comparison of future payments by applying a discounting factor to determine their present value. An investment is deemed profitable if the NPV of all related payments is positive.

Maritime engineering design projects are typically conducted for two main purposes: a) to create detailed designs for the construction and installation of equipment, and b) to provide critical information for decision-making regarding the profitability of an investment. These profitability estimations are performed at different stages of the project, becoming more detailed and accurate as the project progresses.

Evaluations in engineering projects often rely on key financial metrics, with cash flow analysis and NPV being among the most commonly used approaches. These methods help in making informed decisions about the financial viability of investments(Peters et al. 1968, 2018, Sinnott et al. 2019).

The NPV of a project is the sum of the present values of the future cash flows:

$$NPV = \sum_{y=1}^{y=t} \frac{CF_y}{(1+i)^y} \tag{10}$$

Where:

- CF_n is the cash flow in year *y*
- *t* is the project life in years
- *i* is the interest rate.

Cash flows are computed by subtracting the total costs *TC* in year *y* from the revenues *R* in the same period. In this model, 2 revenue streams are considered: 1) from the sale (or reduced use of) Carbon Permits; and 2) from the sale of the Captured CO2. Both Costs and Revenues occur at the end of the period, meaning that the price of Carbon Allowance taken into a consideration for a given year *y* is equal to the price of the said Carbon Allowance in the last trading day of the last month of the year.

To calculate the revenues from sale of carbon permits, several steps were taken. Firstly, the forecasted emissions were multiplied by the share of the sample fleet with CCS systems installed of the total maritime fleet, using gross tonnage as reference. That way the amount of CO2 emitted by the ships with CCS is calculated. This assumes that emissions are directly correlated to the deadweight of the vessels. For the analysis the CCS systems operate at 90% capturing efficiency as stated in the literature. It is assumed that capturing efficiency reflects the CO2 captured, therefore CO2 avoided is equal to CO2 captured. Therefore, the Carbon Dioxide emitted from the vessels with CCS systems is multiplied by 0.9 to evaluate the total captured CO2 *TS*. This is then multiplied by the forecasted trading price of the carbon permits from the given market for that year.

In this analysis, it is also assumed that the captured CO2 is also sold to third parties to be put in geologic formations. The price of CO2 used for enhanced oil extraction has high fluctuations and depends on various factors. Moreover, the cost of storage, transportation, liquefication, etc. vary based on time and distance of transportation. Therefore, based on existing literature a net value of 20€/ton CO2 will be assumed (Vidas, Hugman, & Clapp, 2009; Roussanaly & Grimstad, 2014). This value is represented in the variable *CO2Price* and will be adjusted to inflation in the given period. The mathematical representation of the captured CO2 by *n(y)* and revenues in year *y* is as follows:

$$TS(y) = 0.9 \times Total\ Maritime\ CO2 \times Share\ of\ n(y)\ from\ Global\ fleet \tag{11}$$

$$R(y) = TS \times (Carbon\ permits + CO2Price \times (1+i)^{y}) \tag{12}$$

The Total Costs for year *y* *TC(y)* consist of the total Operational Cost *c(y)*, total Capital Cost *CapY (y)*, and the total cost of the solvent used in year *y*. To calculate the Operational costs and expenses for the MEA solvent, a similar method is used. The price of the MEA solvent per kilogram *Pmea* is determined based on the price in each of the studied regions and is adjusted to inflation. The total cost is the product of the *TS, Pmea*, and a constant of 1.696, as this is how much solvent is required per ton of CO2 captured, according to the literature. The Captured CO2 is calculated in the same way as mentioned. The total costs in year *y* are:

$$TC(y) = TS(y) \times 1.696 \times Pmea + c(y) + CapY\ (y) \tag{13}$$

3.4 Forecasting method

To forecast the values for CO2 emissions and Carbon Allowance Prices, an AAA Exponential Smoothing model was utilized. The AAA version of exponential smoothing, also known as the additive Holt-Winters method, is employed in this study to forecast time series data exhibiting both trend and seasonality. This method is advantageous for data with a linear trend and additive seasonal variations, where the seasonal effects remain roughly constant over time. This model incorporates 3 key components: Level *L*, Trend *T*, and Seasonal Factor *F*. *L* represents the baseline value of the time series after removing trend and seasonal effects (see Eq. 13).

$$L_t=\alpha(Y_t-F_{t-m})+(1-\alpha)(L_{t-1}+T_{t-1}) \tag{14}$$

Here, L_t is the level at time *t*, *Yt* is the observed value at time *t*, F_{t-m} is the seasonal factor from the same season in the previous cycle, and α is the smoothing parameter for the level. Trend *T* captures the rate of increase or decrease in the level over time. The mathematical representation, where T_t is the trend at time *t* and β is the smoothing parameter for trend, looks as follows:

$$T_t=\beta(L_t-L_{t-1})+(1-\beta)T_{t-1} \tag{15}$$

The Seasonal Factor accounts for repeating short term cycles within the data and is expressed with the following equation:

$$F_t=\gamma(Y_t-L_t)+(1-\gamma)F_{t-m} \quad (16)$$

Where F_t is the seasonal factor at time t and γ is the smoothing parameter for seasonality, with m being the length of the seasonal cycle.

The overall forecasting equation is computed:

$$V_{t+k}=L_t+kT_t+F_{t+k-m} \quad (17)$$

Here V_{t+k} is is the forecasted value at time $t+k$ and k is the number of periods ahead to forecast.

Although it is a powerful forecasting method, the additive Holt-Winters model has several limitations. Firstly, it assumes that seasonal effects are additive and constant in magnitude over time. This may not hold true for all data types, especially those with proportional seasonal variations. The accuracy of the method depends heavily on the smoothing parameters (α, β, γ), which need careful selection through optimization. Moreover, its effectiveness declines for long-term forecasts due to compounded errors from the level, trend, and seasonal components.

CHAPTER 4 Data

To perform an analysis about the potential economic benefits of implementing CCS systems in the shipping industry, it is essential to first examine the carbon emission levels from the maritime sector of the analysed countries. To do so, publicly available experimental data on the monthly emission levels provided by the Organisation for Economic Co-operation and Development (OECD) is collected. This experimental dataset includes annual, quarterly, and monthly information on carbon dioxide (CO_2) emissions from maritime transport based on ship-tracking information collected via Automatic Identification System (AIS) transponders, covering all large vessels (above 300 gross tonnage) around the world, accessed via the United Nations Global Platform, from 2019 onwards.

The CO_2 emissions are estimated by the OECD, based on a consistent methodology across countries and include emissions from both domestic and international voyages. The Carbon emissions are classified using the ship-type classification used by the IMO distinguishing between 19 vessel categories such as bulk carriers, tankers, and cruise ships. The dataset contains detailed information on the emissions by vessel types and country. For the purposes of this analysis, the focus is on the total emissions from the maritime sector in the United States, China, and the European countries which have adopted the European Cap-and-Trade system, namely all countries from the European Union excluding the landlocked states (Austria, Hungary, Slovakia, Luxemburg, Czech Republic), Iceland, and Norway.

Table 1.

Descriptive statistics for monthly CO_2 emissions

Note: This table summarizes information about total global monthly emissions for vessels above 300 gross tonnage, spanning from January 2019 to June 2024. The units of measure are tonnes of CO_2.

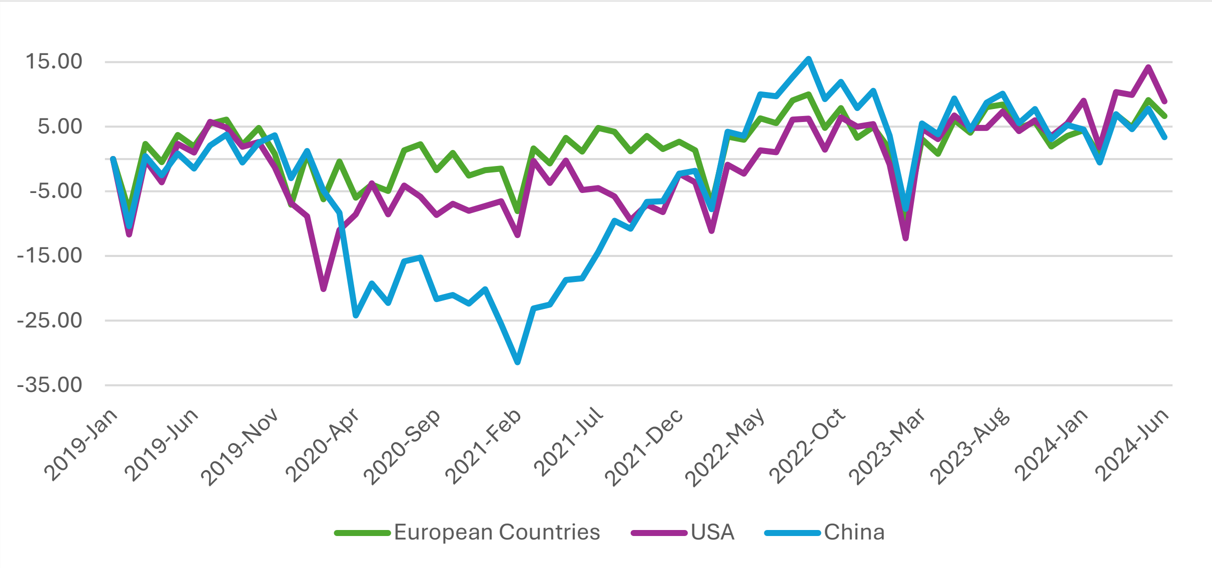
	Obs	Mean	Std.dev	Median	Min	Max
European Countries	66	23 636 300	1 037 287	23 726 526	20 994 692	25 510 052
USA	66	5 444 342	377 435	5 483 845	4 391 574	6 278 436
China	66	3 847 457	467 453	3 987 063	2 726 829	4 594 232

To gain a more comprehensive view, a line chart showcasing the growth rate trends of emissions is provided (see Figure 1). The overall trend depicted in the line chart indicates that while different regions exhibit varying patterns in their CO_2 emissions growth rates, the general trends provide insight into the effectiveness of emission control measures and the impact of economic activities on maritime emissions.

The observed trends and peaks across different regions are likely influenced by various factors, operational adjustments, changes in global trade patterns, and market demands. Peaks in emissions can be tied to periods of heightened industrial activity and commodity trading. The notable peaks around early 2020 might be associated with the disruptions caused by the COVID-19 pandemic, which led to fluctuations in global shipping demand and operational changes.

Figure 1.

Trend in growth rate of total monthly emissions from the maritime industry



Note: This graph was constructed using the information provided by OECD on CO2 emissions per vessel type. The trendlines use the amount of CO2 emitted at the beginning of the dataset (January 2019) as a reference.

To properly perform the Net Present Value analysis, it is essential to estimate how many ships can install the CCS systems. Information on maritime fleet composition was retrieved from UN Trade and Development (UNCTAD). The dataset provides statistics on international maritime transport, detailing the size of the global merchant fleet by flag of registration and type of vessel. Additionally, the data includes the respective shares of countries or regions in the world fleet and their proportions of specific vessel types within their total fleets based on dead-weight tons (DWT). From 2011 onwards, figures on the number of ships and data on ship sizes in gross tonnage (GT) have also been available. According to UNCTAD estimates based on data provided by Lloyd's Register Fairplay (up to 2010) and Clarkson Research Services (from 2011 onwards), the figures encompass seagoing propelled merchant ships of 100 gross tons and above, excluding inland waterway vessels, fishing vessels (from 2011 onwards), military vessels, yachts, and offshore fixed and mobile platforms and barges, with the exception of FPSO (floating production, storage and offloading vessels) and drill ships.

For ships lacking recorded DWT in the raw data, UNCTAD estimates DWT based on the GT and type of the vessel. In 2024, 19,453 ships out of a total of 108,789 (17.9%) lacked a DWT measure. These are primarily small vessels, representing 0.33 percent of the estimated total DWT of the world fleet. This proportion is relatively higher for some individual economies and vessel types.

By combining the 2 datasets, an average number of ships and CO2 emissions for each country can be estimated. For the purpose of simplification, the assumption that amount of GHG emissions is directly related to gross tonnage will be made. For our simulation, it is also assumed that the number of ships stays constant.

Table 2.

Maritime Fleet statistics

	EU	**US**	**China**
Number of ships	11875	3501	9530
Total DWT	291 623 000	13 215 000	133 647 000

Note: The table represents the fleet composition as of 2024 of ships above 100 DWT

To make analysis about the future prices of EU Carbon credits, data from retrieved from Thomson Reuters is utilized. The dataset contains information on carbon pricing history and futures coverage, providing an overview of market activities related to carbon credits. The data provides detailed information on carbon credit prices, trading volumes, and market activity for the Intercontinental Exchange (ICE) and the European Energy Exchange (EEX). However, the study will focus on the prices of the EEX as this exchange which serves the European Market. The dataset contains information from October 2012 to August 2021.

To analyse the pricing dynamics of carbon allowances for the other 2 markets, data was collected from the ICAP Carbon Action website, which provides comprehensive information on the prices of various Emissions Trading Systems (ETS) globally, and the exchange rate to euro at the time of the trading price. Specifically, data was gathered on the prices of California Carbon Allowances (CCAs) and Chinese Emission Allowances (CEA).
Historical price data for California Carbon Allowances (CCAs) is spanning from November 2012 to February 2024, providing a detailed view of the carbon pricing trends in California. Data on Chinese Carbon Market Allowances includes prices from the launch of the national ETS in July 2021 to the present.
The dataset includes key variables for each carbon market: the date on which the carbon allowance price was recorded and the closing price of the carbon allowance in Euros per tonne of CO2 equivalent, reflecting the cost for entities to comply with their emission reduction obligations.
The collected data was processed to ensure quality and suitability for analysis. This involved data cleaning, where missing values and anomalies were handled appropriately by either imputing missing price data using the mean of neighbouring values or excluding them if gaps were substantial. Currency standardization was applied, with all prices recorded in Euros (EUR) to maintain consistency and comparability.
Several graphs and charts were created to visualize the trends and dynamics of carbon prices in the selected markets. Figure 2, 3, and 4 depict the trend in price growth of each of the mentioned cap-and-trade mechanism.

Figure 2.

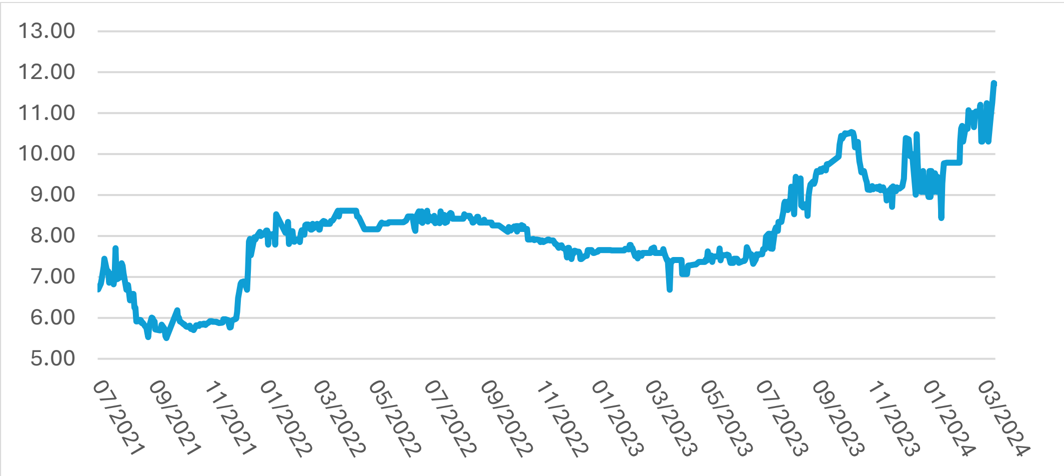
Trendline of EU Carbon Permits trading prices

Note: Prices are in Euro and depict the trading price of 1 ton of CO2

From October 2012 to around 2018, the prices remained relatively stable, fluctuating between 5 and 10 Euros per ton. However, from 2018 onwards, there is a noticeable upward trend. This period marks the beginning of a steady increase, with prices reaching approximately 25 Euros per ton by mid-2019.The most significant rise occurs from 2020 onwards, where prices surge dramatically, peaking at over 55 Euros per ton by April 2021. This sharp increase could be attributed to several factors, including stricter emissions regulations, increased market demand for carbon permits, and heightened awareness of climate policies.

Figure 3.

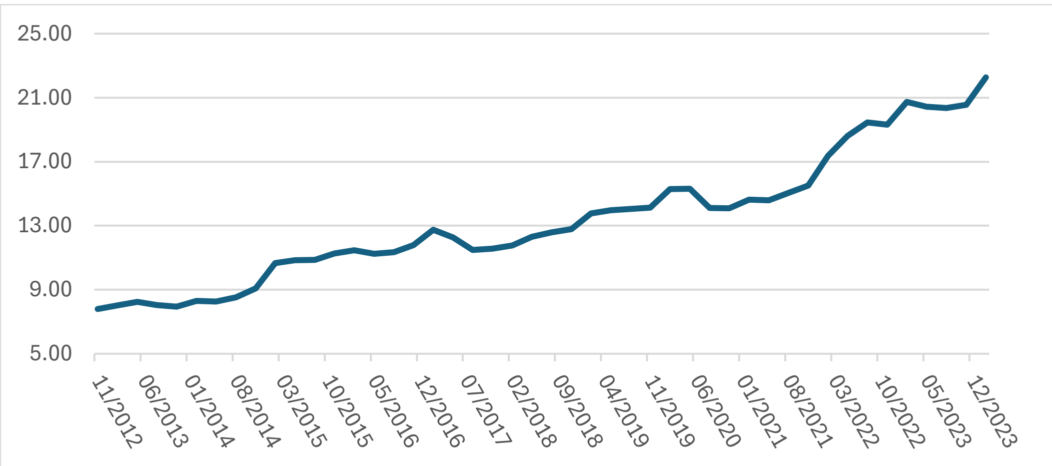
Trendline of China Emission Allowances trading prices



Note: Prices are in Euro and depict the trading price of 1 ton of CO_2

Figure 4.

Trendline of California Carbon Allowances trading prices



Note: Prices are in Euro and depict the trading price of 1 ton of CO2

Actual data about the selling price of the monoethanolamine solvent for each region was acquired from BusinessanalytIQ. Data on the Material Index for Steel Vessel Contracts was retrieved from the Bureu of Labor Statistical Indexes. The dataset provides information about the monthly indexes and spans from January 1988 to July 2019, and uses 1982 as a base year.

CHAPTER 5 Results

Forecasts for the CO_2 emissions in the maritime sector and prices of Carbon Allowances for Europe, the United States, and China were performed using Holt-Winters Exponential Smoothing for the period 2025-2050. Technology penetration was utilized through exponential function in order to simulate the gradual implementation of the technology in the industry. Operating cost reduction through learning curve was integrated into the model based on technology penetration. The maritime fleet for each of the studied regions was aggregated based on number of vessels and total DWT, and a proportional propulsion power for the engine was assigned based on DWT. The initial Capital Expenditure was then calculated for each of the aggregated vessels, based on literature and propulsion power. Capital Expenditures were divided in 26 parts through the assumed life of the CCS system and adjusted to the Material Index for Steel Vessel Contracts. All details about the listed information are provided in Appendix 2.

5.1 Empirical Results

The analysis evaluated the economic impact of implementing carbon capturing systems on ships in Europe, the USA, and China, extending the forecast until 2050. The key analysed metrics include total captured CO_2, revenues from Carbon Permissions and CO_2 sales, total costs, and Net Present Value. The main results are represented in Table 3.

Table 3.

Results of the NPV analysis for Carbon Capturing Systems for the entire period of 2025-2050

	Europe	**US**	**China**
Total Captured CO2 (in million tonnes)	6 187	1 163	1 777
Total Revenues	€ 841,257,359,050	€ 50,711,330,556	€70,384,816,638
Total Costs	€ 371,261,071,482	€ 65,831,829,351	€129,203,161,710
NPV	€ 469,996,287,568	- € 15,120,498,795	- € 58,818,345,072

Note: All monetary values are in euros (€) and are adjusted to represent PV for 2025.

Europe

The implementation of carbon capturing systems on ships in Europe shows a highly favourable outcome. Europe records the highest revenue, amounting to € 841,257,359,050. The total costs for the period are € 371,261,071,482. With 11 875 ships outfitted with carbon capturing systems, the region achieves a significantly positive NPV of € 469,996,287,568. This indicates substantial long-term profitability and financial sustainability through 2050. The CCS systems also produce a positive environmental effect, resulting in the capturing of 6187 million tonnes of CO_2 emissions for the studied period, which amounts to 68.55% of the total greenhouse gas emissions produced in the industry.

USA

The USA presents a mixed financial picture following the implementation of carbon capturing systems. The total revenue for the period is € 50,711,330,556, slightly less than the total costs of € 65,831,829,351. Despite requiring the lowest capital investment due to the lower amount of ships involved and their relatively low propulsion power, the NPV is negative at - € 15,120,498,795, suggesting that, under current financial projections, the implementation of carbon capturing systems is not economically viable in the USA over the long term. However, when it comes to environmental impact, the CCS systems prove to be a highly efficient carbon emission reduction tool. 69.89% of the total produced CO_2 for the period are captured, or 1163 million tonnes of CO_2.

China

China encounters significant financial hurdles in implementing carbon capturing systems. The total revenue from sales of permissions and liquified CO_2 is € 70,384,816,638, which is overshadowed by the remarkably higher total costs of € 129,203,161,710. Operating the second largest fleet of 9530 ships, China's NPV is notably negative at - € 58,818,345,072. This negative NPV highlights severe financial unsustainability in China's maritime emissions operations with the current CCS system implementations through 2050. Regardless of the negative NPV, China experiences the most efficient CO_2 emissions reduction. The captured carbon dioxide amounts to a total of 1777 million tonnes, which is 70.29% of the produced CO_2 by the maritime industry.

5.2 Hypotheses and Discussion

After conducting the analysis, it is important to combine the results to answer the formulated hypotheses. To begin with, the findings related to the first hypothesis will be discussed. Hypothesis 1 is phrased as follows:

H_1: Implementing CCS systems in the maritime industry leads to positive financial outcomes

The results from the regression analysis indicate substantial differences in the financial outcomes of implementing carbon capturing systems on ships across Europe, the USA, and China until 2050. Europe emerges as a clear leader with a highly positive NPV, showcasing the financial viability and profitability of such systems. In contrast, the USA and China face financial challenges, with negative NPVs. As the implementation of CCS is undertaken by private companies which prioritize profitability, this highlights the need for improved financial strategies and policy interventions to ensure the long-term sustainability of carbon capturing initiatives in these regions.

However, it is important to note the limitations in this study. Firstly, the strong assumptions in the model imply that the results should be interpreted as qualitative rather than quantitative. Furthermore, the aggregation of the data for the fleet composition for each of the regions might cause problems related to the predictive power of the forecasts due to uncertain complex interactions between variables. What is more, differences between the regions, such as environmental policies, subsidies, taxes and tax policies, and the availability and quality of port infrastructure for CCS technology are not considered. The accuracy of the forecasts must also be put into question, as the accuracy of the prediction usually decreases as the forecast period extends further into the future. Also, important factors such as the demand for maritime transport, slow steaming, and potential policies and shocks are not accounted for. Due to the listed limitations, analysis for the financial benefits of CCS systems would be significantly more accurate if it is performed on a microeconomic level for a given company rather than macroeconomic basis.

Another factor that is not considered is the monetary value of the CO2 emissions reductions. The improved quality of air can increase life expectancy, productivity, life quality, etc. However, it is extremely hard, if not impossible, to evaluate the environmental benefits in monetary terms due distributional, temporal, and modelling matters.

As the main purpose of Carbon Capturing and Storage systems is to reduce CO_2 emissions, it is needless to say that this aspect has to be studied when evaluating the economic benefits of its implementation. Therefore, the second hypothesis is formulated as follows:

H_2: Implementing CCS systems in the maritime industry leads to substantial reduction in CO_2 emissions

The results from the empirical analysis indicate a positive environmental effect in all three of the studied regions. In each case, the application of CCS systems indicates a reduction of more than 68% in the emitted CO_2 from the maritime industry for the forecasted period. Therefore, it can be concluded that this is a good environmental strategy to decrease the greenhouse gas emissions.

Nonetheless, the forecasting model suffers from the same problems and limitations as the abovementioned. Although the environmental benefits of CCS systems are unquestionable, it is unknown whether a more suitable method will occur in the near future, such as more cost-efficient engine than the diesel one, which runs on zero emission fuels. The uncertainty regarding this matter might disincentivize investors to undertake CCS projects and rather opt for other possibilities.

CHAPTER 6 Conclusion

This thesis studies the economic benefits of implementing onboard post-combustion carbon capture and storage systems on commercial cargo ships. As more and more emphasis is given on the topic of sustainability, options to reduce the CO2 emissions are being explored. But as the technology to fully transition to net-zero fuels without baring detrimental economic consequences is still not available, the research focuses on Carbon Capturing and Storage systems. Little research has been done on the economic benefits of integrating CCS into the maritime industry, with most literature focusing on case studies. The primary purpose of the thesis is to investigate how CCS systems can contribute to reducing carbon emissions in the maritime industry while also assessing their financial viability.

The analysis focuses on three key regions: Europe, the USA, and China, chosen due to their significant share of global maritime activity and distinct carbon allowance systems. The study employs data from empirical research on CCS system efficiency, fleet composition and emissions data from the United Nations Conference on Trade and Development (UNCTAD), and historical trading prices for carbon credits and liquid CO2. The economic feasibility of CCS systems is evaluated using Net Present Value analysis, incorporating projected revenue streams from carbon credits and captured CO2 sales against operational and installation costs. The analysis reveals both promising financial and environmental benefits, although with significant regional disparities. Europe emerges as the most financially viable region with a highly positive NPV, reflecting the profitability and sustainability of CCS implementation. Conversely, the USA and China face economic challenges, with negative NPVs indicating the need for better financial strategies and policy interventions. However, all regions demonstrate substantial reductions in CO2 emissions, validating the environmental efficacy of CCS systems. Despite the promising results, several limitations must be acknowledged, including the assumptions in the forecasting model, the aggregation of data, and the exclusion of potential future technological advancements. Addressing these limitations through more detailed microeconomic analyses and considering the broader environmental benefits beyond direct financial returns can provide a more comprehensive understanding of CCS systems' impact. Ultimately, while CCS technology shows significant potential, its success will depend on continued technological innovation, supportive policies, and strategic financial planning to overcome the challenges identified in this study.

Future research should focus on exploring new carbon capture technologies, assessing the impact of policies on CCS adoption, comparing CCS with other emission reduction methods, and studying long-term environmental benefits. It should also focus on economic incentives, detailed case studies, integrating CCS with other green technologies, market dynamics of carbon credits, cost reduction strategies, and the broader social and economic impacts of CCS adoption.

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Appendix 1.

To compute estimate the relationship between DWT and propulsion power, an ordinary linear regression was utilised. The data used was retrieved from the existing literature. Table 4 represents the values and where they were retrieved from.

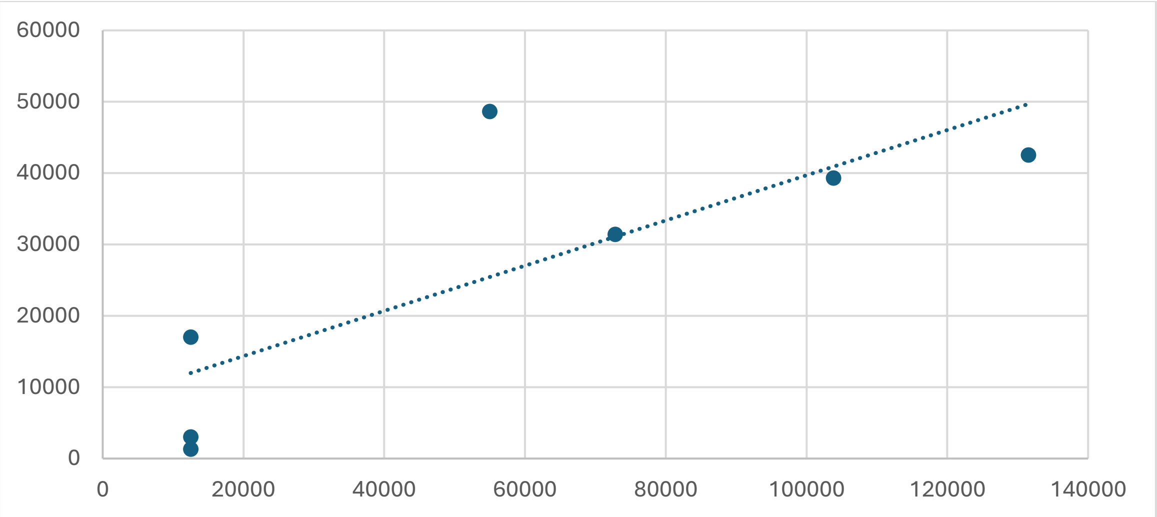
Table 4.

DWT and Propulsion power of case study ships

DWT	Propulsion power	Literature source
55 000	48,600 kW	Zincir et al., 2024
12 500	17,000 kW	Luo & Wang, 2017
12 500	3,000 kW	Feenstra et al., 2019
12 500	1,280 kW	Feenstra et al., 2019
72 800	31,400 kW	Güler & Ergin, 2021
103 838	39,300 kW	Güler & Ergin, 2021
131 529	42,500 kW	Güler & Ergin, 2021

Figure 5.

Scatterplot between DWT and Propulsion Power



Note: X-axis values represent DWT (tonnes) and Y-axis values represent propulsion power in kW

When computing the linear regression, it shows a significant correlation between the dependent and independent variable, with a p-value of 0.032. Therefore, it is safe to assume that the two variable are correlated and can be used to construct the model. Consequently, the homogeneous ships in the model have the parameters represented in Table 5.

Table 5.

Parameters of the homogeneous ships used in the model.

	EU	US	China
Number	11,875	3,501	9,530
Total DWT	291,623,000	13,215,000	133,647,000
DWT per ship	24,558	3,775	14,024
Propulsion power	15,814 kW	9,230 kW	12,477 kW
CAPEX	€ 9,548,267.25	€ 5,572,863.74	€ 7,533,334.48
CapY	€ 367,241.05	€ 214,340.91	€ 289,743.63
MEA Solvent/tCO2	€ 2.49	€ 2.31	€ 1.81

Note: DWT is measured in tonnes, Propulsion power is measured in kW, and All monetary values are in euros (€) and are adjusted to represent PV for 2025.

Appendix 2.

Table 6.

Forecasted Values for the Carbon Allowances until 2050

	EU ETS	CCA	CEA
2025	€ 75.10	€ 23.98	€ 14.26
2026	€ 81.44	€ 25.11	€ 15.59
2027	€ 87.77	€ 26.25	€ 16.92
2028	€ 94.11	€ 27.39	€ 18.26
2029	€ 100.44	€ 28.52	€ 19.61
2030	€ 106.78	€ 29.66	€ 20.95
2031	€ 113.11	€ 30.80	€ 22.29
2032	€ 119.45	€ 31.93	€ 23.63
2033	€ 125.78	€ 33.07	€ 24.97
2034	€ 132.11	€ 34.21	€ 26.32
2035	€ 138.45	€ 35.34	€ 27.66
2036	€ 144.78	€ 36.48	€ 30.34
2037	€ 151.12	€ 37.62	€ 31.69
2038	€ 157.45	€ 38.76	€ 33.03
2039	€ 163.79	€ 39.90	€ 34.37
2040	€ 170.12	€ 41.04	€ 35.71
2041	€ 176.46	€ 42.18	€ 37.05
2042	€ 182.79	€ 43.33	€ 38.40
2043	€ 189.13	€ 44.47	€ 39.74
2044	€ 195.46	€ 45.61	€ 41.08
2045	€ 201.79	€ 46.75	€ 42.42
2046	€ 208.13	€ 47.89	€ 43.76
2047	€ 214.46	€ 49.03	€ 45.11
2048	€ 220.80	€ 50.17	€ 46.23
2049	€ 227.13	€ 51.31	€ 47.40
2050	€ 233.47	€ 52.45	€ 48.57

Note: All values are in Euros and represent the price per ton of CO2 emitted

Table 7.

Total CO2 emissions from the maritime sector

	Total Emissions EU	Total Emissions US	Total Emissions CN
2025	300,399,449	51,430,428	74,206,420
2026	303,929,896	52,974,949	75,772,376
2027	307,460,343	54,519,470	77,338,332
2028	310,990,790	56,063,991	78,904,288
2029	314,521,236	57,608,513	80,470,244
2030	318,248,712	53,485,828	82,589,445
2031	322,098,292	51,766,449	83,984,812
2032	325,947,872	51,314,530	86,517,995
2033	329,797,452	58,877,810	87,913,363
2034	333,647,032	58,283,581	90,446,546
2035	337,496,613	56,145,269	91,841,914
2036	341,346,193	59,336,807	94,375,097
2037	345,195,773	64,963,974	95,770,465
2038	349,045,353	64,368,794	98,303,648
2039	352,894,933	61,652,917	99,699,015
2040	356,744,514	67,872,361	102,232,198
2041	360,552,096	70,518,424	104,457,473
2042	364,334,462	70,176,491	106,307,376
2043	368,116,828	70,557,687	108,157,280
2044	371,899,194	75,142,632	110,007,184
2045	375,681,560	74,031,096	111,857,087
2046	379,463,926	73,280,241	113,706,991
2047	383,246,292	76,166,324	115,556,895
2048	387,028,658	78,531,062	117,406,798
2049	390,810,959	78,348,795	119,256,873
2050	394,593,688	77,042,904	121,134,188

Note: All values are in tonnes of CO2

Table 8.

Values of technological penetration $t_p(y)$, learning curve factor lc(y), inflation coefficient, Material Index for Steel Vessel Contracts vi, and the escalated OPEX per CO2 captured ec(y)

	$t_p(y)$	*lc(y)*	Inflation coef.	*vi*	ec(y)
2025	13.53%	1.0000	1	1.00	€ 52.93
2026	16.49%	1.0000	1.022	1.02	€ 54.09
2027	20.05%	1.0000	1.044484	1.04	€ 55.28
2028	24.33%	1.0000	1.067462648	1.06	€ 56.50
2029	29.41%	1.0000	1.090946826	1.08	€ 57.74
2030	35.37%	0.9300	1.114947656	1.10	€ 54.88
2031	42.21%	0.9300	1.139476505	1.13	€ 56.09
2032	49.93%	0.9300	1.164544988	1.15	€ 57.32
2033	58.42%	0.9300	1.190164978	1.17	€ 58.59
2034	67.55%	0.9300	1.216348607	1.20	€ 59.87
2035	77.13%	0.8649	1.243108277	1.22	€ 56.91
2036	86.88%	0.8649	1.270456659	1.24	€ 58.16
2037	96.46%	0.8649	1.298406705	1.27	€ 59.44
2038	100.00%	0.8649	1.326971653	1.29	€ 60.75
2039	100.00%	0.8649	1.356165029	1.32	€ 62.08
2040	100.00%	0.8044	1.38600066	1.35	€ 59.01
2041	100.00%	0.8044	1.416492674	1.37	€ 60.31
2042	100.00%	0.8044	1.447655513	1.40	€ 61.64
2043	100.00%	0.8044	1.479503934	1.43	€ 62.99
2044	100.00%	0.8044	1.512053021	1.46	€ 64.38
2045	100.00%	0.7481	1.545318187	1.49	€ 61.19
2046	100.00%	0.7481	1.579315187	1.52	€ 62.54
2047	100.00%	0.7481	1.614060122	1.55	€ 63.91
2048	100.00%	0.7481	1.649569444	1.58	€ 65.32
2049	100.00%	0.7481	1.685859972	1.61	€ 66.75
2050	100.00%	0.6957	1.722948891	1.64	€ 63.44