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Implementation of Carbon Accounting in the Shipping Industry: An Exploratory Study

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ABSTRACT

This study explores whether the shipping industry is ready to implement carbon accounting practices to improve environmental sustainability. With the industry heading towards net zero in the near future, there are several reasons why organisations are not ready to embrace new technologies and practices such as carbon accounting, apart from what they are already doing. While many firms have started tracking fuel use and meeting reporting requirements, carbon accounting often requires more than compliance. Hence, readiness is uneven across the sector, especially when companies face tight margins, more complex supply chains and differing customer demands and regulatory expectations. Primary qualitative data was collected through semi-structured, one-to-one interviews with industry experts across different maritime organisations to gain insights into current practices, challenges and opportunities. Through the interviews, the study demonstrates that the adoption of carbon accounting systems is affected by high costs, enforcement gaps, limited understanding and low willingness. Interviewees also identified opportunities, including long-term cost savings through fuel optimisation, market differentiation as well as the need for further research and development to improve the lifecycle performance and cost-competitiveness of low-emission options. Then, the PESTEL framework is used to examine the factors that shape adoption of carbon accounting systems in the shipping industry. Additionally, existing research on carbon accounting in other industries and countries was reviewed and revealed its benefits and impact on the organisation and environment. Ultimately, the study argues that there is a need for a more comprehensive and long-term solution. Better financial products and incentives to aid the industry must be provided for there to be a higher adoption rate of carbon accounting practices, especially for smaller players that lack capital and technical resources. Stronger regulations can increase participation and ensure consistent implementation. However, more work must be done to address the concerns and highlight the benefits of the adoption of carbon accounting in the maritime sector so that the shipping industry can move towards a more sustainable future.

Keywords: carbon accounting, shipping industry, sustainability, decarbonisation, GHG emissions.

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1 INTRODUCTION

One of the major topics of discussion in the shipping industry today is green shipping. Global climate change continues to be of great concern. The largest contributor to climate change is the burning of fossil fuels, which accounts for 75% of the world's greenhouse gas (GHG) emissions and 90% of all carbon dioxide (CO_2) emissions (United Nations, n.d.-a). According to Morante (2022) from the United Nations Conference on Trade and Development, approximately 2.8% of total worldwide GHG emissions are generated by the maritime industry. This is attributed to the swift expansion of the industry, its heavy reliance on carbon-intensive fuels and the substantial scale of shipping operations (Morante, 2022). The effects of human-caused climate change are not only worrying but also irreversible. "Intense droughts, water scarcity, severe fires, rising sea levels, flooding, melting polar ice, catastrophic storms and declining biodiversity" (United Nations, n.d.-b) are just some of the current after-effects of global warming.

As a result of climate change, the International Maritime Organization (IMO) has come up with strategies for the reduction of GHG emissions from ships. On 7 July 2023, the IMO adopted the "2023 IMO Strategy on Reduction of GHG Emissions from Ships, with enhanced targets to tackle harmful emissions" (International Maritime Organization, 2023). The main aim of this strategy is to lower CO_2 emissions by no less than 40% and to integrate technologies, fuels and energy sources with minimal or no GHG emissions at all, ultimately making up only 10% of the energy consumption in international shipping by 2023 (International Maritime Organization, 2023). The overarching goal of this strategy is to reach net zero GHG emissions close to the year 2050 with indicative checkpoints along the way.

With the industry coming together to work towards decarbonisation, shipping companies require tools to aid them in tracking and monitoring their GHG emissions. Through consistent monitoring of GHG emissions, operators can ensure they are compliant with and adhering to regulations and implement necessary adjustments to decrease emissions. GHG emission monitoring data can also be used to compute a vessel's fuel usage, which ideally could result in extra cost savings and emission reductions in the long run. According to the GHG Protocol Corporate Standard (Greenhouse Gas Protocol, n.d.), GHG emissions are grouped according to scopes. In particular, Scope 1 refers to direct emissions from sources owned or controlled by the company, Scope 2 covers indirect emissions from the generation of energy used by the company and Scope 3 covers all other indirect emissions from the company's value chain that are not included in Scopes 1 and 2. There are a few ways to measure GHG emissions and carbon accounting is one of them.

Carbon accounting is a method used to assess the amount of GHG emissions emitted by an organisation. Similar to how financial accounting quantifies financial impact, carbon accounting quantifies the environmental impact produced by its business activities (Farbstein et al., 2023). The main aim of carbon accounting is to measure, track and report the amount of GHGs generated by an organisation. According to Ascui and Lovell (2012), carbon accounting is a complex and multifaceted concept that involves navigating different interpretations, jurisdictions and terminology. There are different scopes of emissions such as corporate or project basis, different levels of accounting such as on an industry, national or global level, different requirements which could be mandatory or voluntary and different purposes like research or compliance when it comes to carbon accounting (Ascui & Lovell, 2012).

The current status of carbon accounting reflects the growing significance of its role in addressing climate change. Regulatory bodies worldwide have increasingly mandated carbon reporting, with examples like the European Union's Emissions Trading System (EU ETS) expanding to cover more sectors and regions (European Commission, 2023). Corporations are voluntarily committing to carbon reduction targets and integrating carbon accounting into their sustainability strategies with initiatives such as the Science Based Targets initiative (SBTi), which has garnered over 2,000 corporate commitments (Science Based Targets initiative, n.d.).

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Technological innovations such as remote sensing, satellite imagery and blockchain are enhancing the accuracy and efficiency of carbon accounting, facilitating better monitoring and measurement of emissions across industries (Datta, 2023). Moreover, international agreements like the Paris Agreement foster cooperation and standardisation of carbon accounting methodologies (United Nations Framework Convention on Climate Change [UNFCCC], n.d.), emphasizing the global effort needed to mitigate climate change.

Carbon accounting is something that is already being practised in some countries, industries and corporations, though it is still relatively new to the shipping industry. It brings about several competitive advantages to the value chain of an organisation. A study by the Carbon Disclosure Project (CDP) found that organisations with some form of carbon management strategy managed to save US$19.3 billion collectively (CDP & Carbon Trust, 2019). Supply chains can save substantial amounts of money by identifying inefficiencies and areas for improvement using carbon accounting. When a business identifies where energy consumption is highest, it can take action to reduce it and hence lower operating costs. As environmental regulations tighten and green plans are formed, companies with comprehensive carbon accounting can proactively monitor emissions and adapt to future changes. This not only avoids potential fines but also paves the way for a more sustainable future with potentially lower compliance costs (Buggie & Farbstein, 2024). Lastly, carbon accounting ensures transparency and credibility in emission reports, showcasing a genuine commitment to environmental responsibility beyond just claims.

Hence, the significance of this study lies in its potential to catalyse meaningful change within the shipping industry and contribute to broader societal efforts towards environmental sustainability. By addressing key research questions related to the feasibility of carbon accounting systems (CASs) in maritime operations, valuable insights can be derived from industry players' viewpoints. While many studies have explored the challenges surrounding carbon accounting, much of the existing research has focused on the technical and methodological aspects. There is limited research that examines the readiness of shipping firms to adopt carbon accounting as a management practice from the perspective of industry practitioners. This study addresses this gap by collecting primary qualitative data through semi-structured, one-to-one interviews with industry experts and examining the wider factors that shape adoption across the sector. These shall inform more targeted policy responses and support the industry in moving towards a more sustainable future. Despite growing regulatory and industry focus on decarbonisation, research on carbon accounting in the maritime sector remains fragmented. There is limited understanding of how emissions can be measured across entire voyage operations, integrated with alternative fuel systems and translated into meaningful sustainability outcomes.

These gaps are significant given the complexity of shipping value chains and the uncertainties surrounding alternative fuel adoption, particularly in terms of measurement standards, data transparency and implementation. Therefore, further exploratory research is needed to examine the practical and strategic role of carbon accounting in this context. To address these gaps, this study is guided by the following research questions and corresponding objectives:

1. How can carbon emissions be measured and managed throughout the entire voyage operations? This question arises from the lack of integrated, end-to-end emission tracking frameworks in existing literature. The first objective of the study is to find out more information about the techniques, technologies and practices that are required or need to be employed to monitor and manage carbon emissions from the start to the end of a voyage.

2. What are the opportunities and challenges associated with implementing carbon accounting systems in the alternative fuel sector? Given the limited research on carbon accounting within emerging fuel transitions, this question seeks to explore both the potential benefits and the barriers to implementation. The second study objective is therefore to analyse the issues and potential advantages faced by industry stakeholders when it comes to adopting CASs within the alternative fuel industry.

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3. What is the potential impact of carbon accounting on environmental sustainability? While carbon accounting is often promoted as a sustainability tool, its actual impact remains underexplored. Thus, the third study objective is to find out how carbon accounting will affect environmental sustainability and whether it can contribute to an organisation's commitment to reduce carbon emissions and ensure long-term sustainability.

The scope of this study will be focused on the global shipping industry; however, other industries that are using CASs may be referenced for examples and used as a comparison or benchmark. Data will come from multiple organisations and will be focused on the entirety of the value chain. This paper is structured as follows: the literature review is presented first, followed by the research methodology, results and finally the conclusion with recommendations.

2 LITERATURE REVIEW

This section critically analyses existing research on carbon accounting in the shipping industry. It will focus on measurements and management, opportunities and challenges in implementing CASs and the potential impact on environmental sustainability.

2.1 Carbon Emissions Measurement and Management

The global shipping industry is a significant contributor to GHG emissions, accounting for an estimated 2.8% of global GHG emissions (Morante, 2022). To address this challenge, accurate measurement and management of carbon emissions from ships are crucial.

To combat climate change and promote sustainable practices within the maritime industry, the European Union (EU) passed a regulation on the monitoring, reporting and verification (MRV) of carbon dioxide emissions from maritime transport in 2015 (Regulation (EU) 2015/757, 2015). The primary objective of the regulation is to collect data on CO_2 emissions and other relevant information from vessels to measure their environmental performance. It only applies to vessels above 5,000 gross tons that call at EU ports or operate in EU waters.

The EU MRV regulation outlines several methods for calculating CO_2 emissions. These methods, primarily focused on fuel consumption, utilise a combination of data sources like Bunker Fuel Delivery Notes (BDNs), periodic fuel tank stocktakes, on-board fuel tank monitoring and flow meter readings from combustion processes. Companies then use a standardised formula that incorporates emission factors provided by the Intergovernmental Panel on Climate Change (IPCC) to convert fuel consumption data into CO_2 emissions. Independent verifiers ensure the accuracy and reliability of the reported data, further strengthening the integrity of the system.

While the EU MRV represents a significant step towards monitoring CO_2 emissions from ships, numerous limitations hinder its effectiveness. Fedi (2016) highlighted that because the MRV system is regional, applying to only EU ports through Port State Control (PSC), it would only have international effects, which is not enough for a global industry like shipping, which requires universal solutions. This fragmented approach weakens international maritime law. Poulsen et al. (2021) stressed MRV's data validity, stating that ocean and weather conditions play a part in fuel consumption and are beyond human control. Identical ships on similar voyages can have vastly different fuel consumption due to weather variations (International Chamber of Shipping [ICS], 2014, as cited in Poulsen et al., 2021), which ultimately affect the validity of the MRV calculations.

Apart from the EU's MRV regulation, there have also been several studies that have addressed methodologies for measuring and managing carbon emissions throughout the voyage operations of ships. The two main methodologies identified are the top-down approach and the bottom-up approach as recommended by the IPCC (Eyring et al., 2010, as cited in Semab et al., 2023; Yang & Ma, 2019, as cited in Semab et al., 2023).

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In the top-down approach, emissions are calculated without considering location and are based on fuel usage and emission factors. In contrast, the bottom-up approach directly estimates emissions for individual ships and specific routes within a particular region. This is achieved by considering the ship's characteristics, movements and relevant emission factors (Eyring et al., 2010, as cited in Semab et al., 2023). The IMO has also employed the top-down approach leveraging fuel statistics and the bottom-up approach, utilising ship activity data to assess global shipping emissions across its studies (IMO, 2009, 2015, 2021b, as cited in Semab et al., 2023).

However, limitations exist with these methods, as highlighted by Semab et al. (2023), who pointed out that the third and fourth IMO GHG studies (IMO, 2015; 2021b, as cited in Semab et al., 2023) had major gaps in the international fuel consumption records for specific years (e.g., 2012 and 2018). This data, which the IMO relies on and is provided by the International Energy Agency (IEA), may not deliver a full breakdown of fuel consumption across all vessel types and sizes.

Additionally, Automatic Identification System (AIS) data that is used for the bottom-up approach only covers ships exceeding 100 Gross Tonnage (GT) that are registered with an IMO number. Since fishing vessels and harbour crafts typically fall below 100 GT and often lack IMO registration, their emissions data is not captured through AIS, potentially leading to underestimates of total shipping emissions.

2.2 Opportunities and Challenges in Implementing CASs in the Alternative Fuel Sector

Alternative fuels in the shipping industry are often considered "clean energy" because they release lower levels of emissions during the burning of the fuel itself. While emissions from alternative fuels may be lower at this stage of their lifecycle, the opportunity to implement CASs lies in considering the carbon emissions produced from alternative fuels throughout the entirety of their lifecycle. Research from Al-Enazi et al. (2021) states that by considering the entire lifecycle (as depicted in Figure 1) of fuels, different results may surface than if the focus was solely on emissions at the point of consumption. In the terms "grey hydrogen" and "grey ammonia", "grey" often refers to a carbon-based fuel that is used as an input in the manufacturing or production process of another fuel (Al-Enazi et al., 2021). Hence, the production of alternative fuels may still involve the consumption of fossil fuels, potentially leading to carbon emissions and environmental impacts associated with the extraction and processing of those fuels.

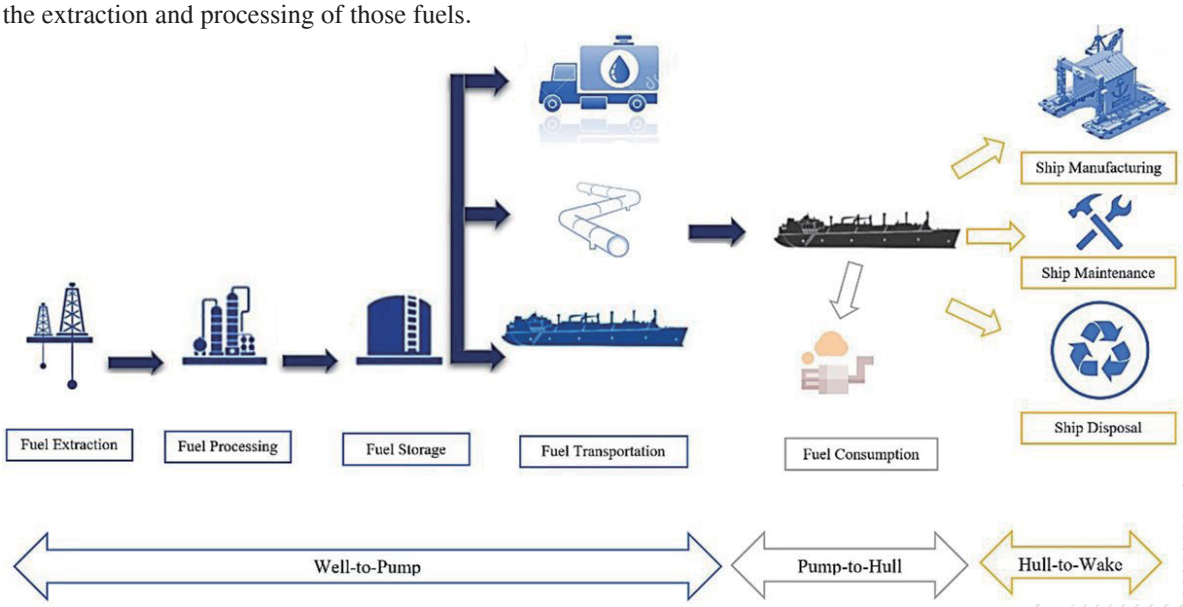

Figure 1. Stages of life cycle assessment for maritime transportation.

Note. Reprinted from "A review of cleaner alternative fuels for maritime transportation", by Al-Enazi et al. (2021). Energy Reports, 7, 1962–1985.

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According to Al-Enazi et al. (2021), different types of alternative fuels have different types of lifecycle emission challenges, which are further illustrated in Table 1. Thus, CASs can be used to highlight cleaner options within the alternative fuel spectrum. Carbon accounting will shed light on actual emissions associated with supposedly clean energy sources throughout their lifecycle, prompting efforts to improve sustainability.

Table 1. Drawbacks of alternative fuels.

Alternative Fuel Type	Limitations
Hydrogen	Hydrogen fuel has the potential to be part of a clean energy future, alongside other environmentally friendly options. However, for hydrogen to truly qualify as clean, the processes used to create and use it must also be clean (United Nations Environment Program [UNEP], 2006, as cited in Al-Enazi et al., 2021).
Ammonia	Current ammonia production methods release 1.5 to 2.5 tonnes of carbon dioxide for every tonne of ammonia produced (Bicer et al., 2016, as cited in Al-Enazi et al., 2021).
Liquified Natural Gas (LNG)	A significant environmental concern with using natural gas, which consists primarily of methane, as a ship fuel is methane leakage, or "methane slippage". This leakage of unburned methane into the atmosphere has a much higher GHG impact compared to CO_2 (Al-Enazi et al., 2021). Although natural gas combustion itself might release less CO_2 compared to some other fuels, studies like Manouchehrinia et al. (2020) (as cited in Al-Enazi et al., 2021) highlight that a significant portion (around 82%) of its lifecycle emissions occur during transport and use (downstream). While LNG may boast lower upstream emissions compared to marine diesel, the high impact of methane leakage throughout its lifecycle makes its overall attractiveness as a clean fuel debatable (Al-Enazi et al., 2021).

While there are opportunities, there are also several challenges when it comes to implementing CASs in the alternative fuel industry. The technological readiness of ships is one such challenge. Retrofitting existing ships for alternative fuels is costly. According to DNV (2023), the limited availability of shipyards for conversions could potentially create bottlenecks, while concerns about cost overruns arise due to the complexity of these projects and uncertainties surrounding best practices. Furthermore, shipowners are concerned about the higher price of alternative fuels and require confidence that their customers will cover the additional costs before investing in expensive retrofits (DNV, 2023). Another challenge is the competition for resources. While the maritime industry seeks to adopt alternative fuels, other sectors are also vying for the same resources, creating a complex dynamic. For instance, electrolysis, which is the process of producing hydrogen, uses large amounts of water. This can be problematic in regions that are already water-scarce and competition from agriculture and other industries also exists (Tonelli et al., 2023).

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2.3 Impact on Environmental Sustainability

The impact of CASs on environmental sustainability has been a topic of extensive discussion and analysis within academic literature. Carbon accounting provides organisations and industries with the ability to produce reports that provide information about the amount of carbon emissions produced (Okafor et al., 2022). These reports serve as a measure of environmental performance, indicating how well a company is managing and reducing its carbon footprint. Analysing these reports can help a company assess its impact on the environment and identify areas where improvements can be made (Okafor et al., 2022). The manufacturing industry is one such industry that has shown a need for standardised carbon accounting practices (Jafar & Kartikasari, 2009, as cited in Okafor et al., 2022). This indicates that there is a growing recognition among industry professionals that carbon accounting is necessary for effective environmental management. In Kazemian et al. (2022)'s study of carbon management accounting (CMA) practices in Australia's high carbon-emission industries, findings revealed that a substantial number of respondents felt that carbon-related information was useful for understanding the company's carbon footprint, caring for their companies' environmental impacts and having a better understanding of the consumption of their companies' energy resources. Comello et al. (2023) also argue that a consistent standard of carbon emission reporting enhances accountability and transparency, which can incentivise the adoption of cleaner technologies and operational practices, ultimately reducing the industry's carbon footprint. In terms of the EU MRV regulation, according to the European Commission Regulatory Scrutiny Board (2018), the impact assessment showed that by choosing the preferred option, there would be a 2% enhancement in energy efficiency, which will lead to a decrease in CO_2 emissions. In addition to the decrease in CO_2, other GHGs will also be reduced.

While there has not been much research done on CASs in the shipping industry, it is clear from research on other industries and countries that CASs do impact environmental sustainability.

However, amidst the optimism surrounding carbon accounting, scholars like Marlowe and Clarke (2022) caution against carbon accounting focusing purely on measurement, overlooking action. Carbon accounting is valuable, but if not effectively utilised, it can become a mere administrative burden, hindering efforts to achieve real and tangible environmental sustainability goals.

3 RESEARCH METHODS

3.1 Research Design

To answer the research questions, an exploratory study approach was used. An exploratory study helped in gathering preliminary information and insights. It also helped to assess whether conducting a more extensive and resource-intensive feasibility study on CASs in the shipping industry was justified, because of the insights it provided on opportunities and limitations and whether they warranted further investigation. Additionally, literature reviews, industry reports, news articles and whitepapers were accessed to enhance the depth and insights of this study.

Since there are no universal CASs, conducting interviews was an ideal option to ascertain the different ways the companies are dealing with this issue. Gathering information through interviews also helps to understand the current status of shipping companies' efforts and how they are dealing with carbon emissions and CASs. The interviews were based on a few structured questions, designed to gather comprehensive insights from a diverse range of respondents within the shipping industry. The questions were carefully crafted to cover various aspects related to carbon emissions management and the implementation of CASs in shipping companies.

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Approaching the interviewees involved a multi-step process. Initially, contact was established with the relevant individuals and, upon obtaining consent and interest in participation, personalised invitations were sent out. The main areas addressed through the interviews encompassed current practices in managing carbon emissions, awareness and perceptions of CASs, barriers to and drivers for adoption and implementation and opinions regarding the future trajectory of carbon emissions management in the industry. By addressing these main themes, the interviews aimed to provide a comprehensive understanding of the current landscape of carbon emissions management and the potential role of CASs in advancing environmental sustainability within the shipping industry.

3.2 Data Collection

Primary qualitative data was collected through in-depth interviews, particularly semi-structured, one-to-one interviews with industry experts from different maritime organisations. From these interviews, more information on the research objectives was obtained.

A format for the interview with similar questions was provided to all the interviewees. This was to ensure that the approach was focused and would not be diverted.

The standard questions that were provided were derived from the three research questions. The interviews covered three main themes:

– Current emissions measurement and management in voyage operations: how organisations measure, monitor, and control carbon emissions across the voyage, including common tools, techniques, and limitations.

– Adoption of CASs in the alternative fuel context: key barriers to implementation, perceived benefits/opportunities, and how the industry has responded and learned from early adoption efforts.

– Environmental sustainability impact of CASs: how CASs support emissions reduction and long-term sustainability goals, including examples of positive outcomes as well as potential drawbacks of relying on CASs.

The interviews were conducted both online and face-to-face and lasted at least 30 minutes. A total of three individuals were interviewed and responses were recorded with consent. The interviewees were selected through purposive sampling to ensure representation across different sectors of the maritime value chain. While the sample size is small, this is consistent with the exploratory nature of the study, which aims to gather preliminary insights rather than to generalise the findings to the entire shipping industry. Each interviewee is in a senior position at their organisation and has direct experience with carbon emissions management. The inclusion of an interviewee from the Oil & Gas sector is justified as the sector is a major stakeholder in the maritime industry and operates large fleets. Table 2 shows the interviewee demographics. The guiding questions are presented in the Appendix.

Table 2. Interviewee demographics.

Interviewee	Job Role	Sector	Range of Employees
A	Senior Fleet Operations Manager	Oil & Gas	40,000
B	Operations Manager	Ship Agency	50
C	Fleet Director	Ship Management	2,000

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3.3 Analysis

Thematic analysis was used to identify recurring themes, patterns and trends related to the research objectives, where interview transcripts were categorised to extract meaningful insights. Fishbone diagram analysis was used to customise the fishbone diagram to the project, where the head represents the challenges and the bones represent the different types of issues that arise when implementing a new initiative in a large industry like shipping. The PESTEL analysis was then used to understand the external macro-environmental factors (Perera, 2018) that can impact the implementation of CASs in the shipping industry and to identify the opportunities and challenges before implementation. The PESTEL analysis draws primarily on the interview findings and is supported by existing literature to contextualise the results within the broader macro-environmental landscape.

4 RESULTS AND DISCUSSION

In this section, the results of the interviews are presented and further discussed. Through careful examination of the data, light will be shed on the intricacies of carbon emissions management and the feasibility of implementing CASs within the shipping industry. The results will be presented according to the various themes identified in the responses.

4.1 Analysing Current Carbon Emissions Measurement and Management

4.1.1 Current practices

The current practices of managing carbon emissions according to interviewees A and C's organisations are listed in Table 3.

Table 3. Interviewees' current practices.

Interviewee	Current Carbon Emissions Measurement Practice
A	An IMO-regulated mathematical formula is used. There is a different mathematical formula for different types of fuel that is based on consumption. A carbon emission multiplier is tied to each type of fuel. Depending on which type of fuel is used, the amount will be multiplied by the respective multiplier. While it is hypothetical, it is supposedly reasonably accurate for the purposes of measuring carbon emissions. Hence, the baseline for carbon emissions is fuel consumption, not an actual measurement of how much carbon is truly being emitted.
B	Not Applicable
C	Carbon emissions are measured based on the main and auxiliary engine shop tests which are carried out prior to putting the engines into service. At present, there are technologies fitted on board such as the Exhaust Gas Scrubber System which are used to reduce CO_2 and SO_x emissions. Additional technologies are also used to reduce fuel consumption/increase the vessel efficiency and thereby reduce the CO_2 emissions.

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According to the responses, it appears that there is a lack of standardisation between the approaches taken to measure carbon emissions. While interviewee A relies on a standardised mathematical formula established by the IMO, interviewee C uses a more nuanced approach that combines pre-service engine testing and emission reduction technologies onboard.

IMO's formula acts as a baseline for carbon emission measurement; however, because it uses fuel consumption data, it is possible to miss out on certain variations in emissions that may occur during operations. Hence, it raises the question of whether the IMO formula is sufficient for all purposes and whether a more precise and standardised method is necessary.

4.1.2 Strengths & weaknesses of current practices

Interviewee A emphasised the simplicity and speed of the current method as a good starting point for measuring emissions. However, they acknowledged the limitations in terms of long-term accuracy and advocated for affordable on-board measurement equipment. Interviewee C mentioned that the shop tests include a direct assessment of emissions from engine operations and hence are accurate, but these methods may not capture emission variations during actual voyage conditions.

While the current practices serve as a good starting point for initial assessments and emission control efforts, there is a need for a more comprehensive and long-term method with better accuracy to capture the fluctuations that occur during actual operations and go beyond shop tests to gather a more holistic picture of a vessel's emissions.

4.1.3 Adequacy of current practices

The interviewees highlighted several points regarding whether the current approaches to carbon emissions management in the shipping industry are sufficient and satisfactory. There was consensus that despite ongoing efforts, there is still a need for continuous improvement. Firstly, the lack of industry participation could be hindering the success of emission reduction efforts, which currently seem to be concentrated within specific companies. Secondly, concerns were raised about the cost burdens placed on shipowners, considering the industry's often limited profit margins. The need for a balanced approach that considers economic viability alongside environmental goals was emphasised.

A recurring theme in the responses is the challenge of balancing environmental considerations with economic viability. This highlights the need for a multifaceted approach that considers both aspects.

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4.2 Challenges and Opportunities

4.2.1 Challenges

Numerous challenges were identified in the interviews concerning implementing CASs. As illustrated in Figure 2, these challenges can be broadly categorised into four main areas: cost, enforcement issues, lack of understanding and lack of willingness. Each of these categories encompasses specific sub-branches that contribute to the overall difficulty of adopting and enforcing carbon accounting practices within the industry.

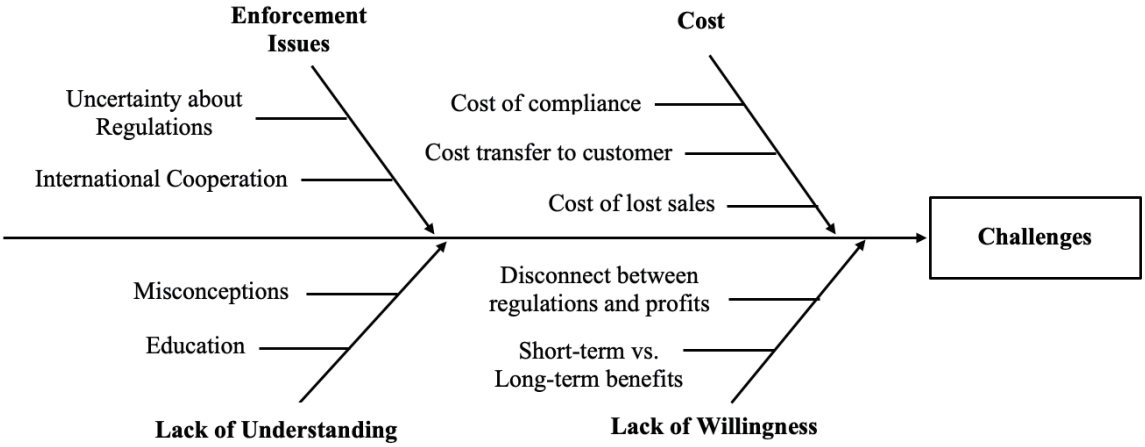

Figure 2. Fishbone diagram structured according to challenges.

Table 4 highlights that while the challenges differ in nature, they collectively create barriers that limit the effective implementation of CASs.

Table 4. Key challenges and implications.

Challenge	Evidence from Interviews	Implication for CAS Implementation
Cost	High cost of compliance Cost transfer to customers Potential loss of sales	Creates a cost–compliance trade-off, discouraging adoption
Enforcement Issues	Uncertainty about regulations Lack of international cooperation Fragmented enforcement	Weakens incentives for compliance and delays implementation
Lack of Understanding	Misconceptions about emissions Limited lifecycle awareness Perceived complexity	Leads to resistance and slow adoption
Lack of Willingness	Disconnect between costs and profits Short-term priorities	Reduces motivation to invest in CASs

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Cost

The high costs associated with measuring and managing carbon emissions as well as implementing some form of CAS in the shipping industry are a major hurdle that was brought up by the interviewees. Firstly, the cost of compliance, in which there is a significant financial burden associated with implementing CASs. This can be a barrier for shipowners, especially considering the industry's often limited profit margins. Secondly, the question of which stakeholder absorbs the costs that ensue together with implementing CASs. If costs are passed on to customers in the form of higher transportation fees, concerns about affordability will develop, along with potential economic disruptions. While environmental goals are important, excessively high costs could lead to resistance from customers. Lastly, the cost of lost sales. High transportation expenses resulting from endeavours to reduce carbon emissions may lead customers to explore less eco-friendly alternatives, potentially resulting in decreased sales for shipping firms. There is a cost–compliance conundrum based on the responses. Hence, shipowners face a difficult choice between environmental responsibility and financial viability.

Enforcement Issues

The importance of robust and consistent enforcement, or the lack thereof, is a challenge when it comes to sustainability efforts. Due to the uncertainty about regulations and enforcement, companies have perceptions that carbon accounting or CASs are not necessary. When regulations are weak or inconsistent, companies might be more inclined to prioritise short-term cost savings and choose to pay fines for non-compliance rather than invest in CASs, which undermines the effectiveness of the regulations. International cooperation is also an issue. The global shipping industry operates across diverse maritime jurisdictions with varying regulations and enforcement practices, creating a fragmented regulatory landscape. This makes it difficult to achieve coordinated enforcement efforts on a global scale. The distinction between flag state control and port state control also creates a challenge whereby a vessel may not be subjected to strict enforcement measures by its flag state but could encounter them in a different port state with stricter regulations.

Lack of Understanding

One misconception highlighted through the interviews was the downplaying of the shipping industry's contribution to global emissions. While the amount may be lower than in some other sectors, even a small percentage from a vast industry like shipping can have a significant impact. Furthermore, the interviewees' limited response regarding the entire value chain and their sole focus on operational emissions suggests a misconception about the lifecycle of GHG emissions. The responses shed light on the limited awareness of the topic of carbon accounting. There is a lack of understanding of the purpose and benefits of CASs. Misconceptions about the complexity and the perceived burden of implementing this system indicate a strong resistance towards its adoption. As the topic of carbon accounting is relatively new in the shipping industry, interviewees mentioned how the industry needs to facilitate knowledge sharing and dissemination of best practices so that companies can accelerate the adoption of such initiatives. Without a clear understanding of the need for CASs and the potential advantages they offer, stakeholders in the industry may be hesitant to embrace them. If the industry remains resistant to change and unwilling to invest in new practices, implementing CASs will be significantly more challenging. A positive and proactive mindset towards environmental sustainability is essential.

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Lack of Willingness

There was a unanimous lack of willingness from the interviewees towards adopting CASs and green shipping initiatives in general. Shipowners in particular would find a disconnect between regulations and profits. Although they would bear the brunt of the cost of implementing CASs and emission-reduction technologies, they may not be the ones reaping the majority of the financial gains from a more sustainable shipping industry. Profits in the industry are distributed across various stakeholders, such as cargo owners, freight forwarders and port operators. If the financial burden falls completely on shipowners while the benefits are more widely distributed, it disincentiveses shipowners from fully embracing CASs. There is also the potential conflict between short-term financial considerations and long-term environmental goals. Shipping companies prioritise immediate profitability over long-term environmental benefits, especially if the returns on investment in cleaner technologies are ambiguous or perceived as slow to materialise. Shareholders may prioritise short-term gains, which places pressure on publicly traded companies and thus may struggle to justify long-term investments in sustainability initiatives. Without a clear long-term vision and financial incentives, shipping companies are less likely to implement CASs.

4.2.2 Opportunities

While the interviewees focused heavily on the challenges, there were still some opportunities that were brought up. Firstly, the potential for long-term cost savings through fuel optimisation was brought up. Tracking and measuring emissions will allow companies to consume fuel more intentionally. A more sustainable business image could also attract more environmentally conscious customers. By embracing carbon accounting and investing in such initiatives, the opportunity to differentiate themselves in the market arises. The acknowledgement of the high costs of alternative fuels and whether they are truly "zero-emission" also highlights the need for further research and development. This could lead to advancements in cleaner and more efficient fuels throughout their entire lifecycle that are still cost-competitive with traditional options. Table 5 summarises the key opportunities of carbon accounting.

Table 5. Key opportunities of carbon accounting.

Opportunity	Description
Fuel Optimisation	Tracking and measuring emissions allows companies to consume fuel more intentionally
Market Differentiation	A more sustainable business image can attract environmentally conscious customers
Innovation in Alternative Fuels	Highlights the need for further research and development
Competitive Positioning	Opportunity to differentiate in the market

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4.3 Potential Impact of Carbon Accounting on Environmental Sustainability

To gain a comprehensive understanding of the potential environmental impact of carbon accounting, we will utilise a PESTEL analysis framework. This framework will allow us to examine the interplay of Political, Economic, Social, Technological, Environmental and Legal factors based on the interview responses. As shown in Figure 3, the PESTEL analysis provides a holistic picture of the potential benefits and challenges associated with carbon accounting for environmental sustainability in the shipping industry.

Figure 3. Potential impact on environmental sustainability.

Political

As the primary international regulatory body for the shipping industry, the IMO is pushing the industry towards decarbonisation with targets set for emission reduction such as the usage of alternative zero or near-zero GHG fuels by 2030 and net zero by 2050 (International Maritime Organization, n.d.). This creates a political environment favouring the adoption of CASs as a tool for monitoring and managing carbon emissions, ultimately leading to environmental sustainability. However, the interviewees felt that the implementation of carbon accounting or CASs could be driven by stricter and clearer international regulations on shipping emissions. This is consistent with research from Bach and Hansen (2023), which found that the lack of consensus and uncertainty surrounding IMO's role poses significant obstacles to the implementation of further regulations on GHG emissions from ships.

Individual countries may implement stricter or more specific regulations on top of IMO guidelines, but this could lead to a patchwork of regulations across different jurisdictions, creating complexity for shipping companies operating worldwide. Some examples include the EU ETS, which creates an additional layer of regulation for shipping companies operating in European waters. The California Air Resources Board (CARB) also has stricter regulations compared to IMO requirements in which there are lower emission limits for specific pollutants and it is compulsory to use cleaner fuels or shore power while at berth (Walton, 2023). Due to the complexities arising from potentially conflicting national regulations, achieving a uniform and rapid implementation of CASs and observing their full impact on environmental sustainability might be challenging in the current political environment.

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Economic

From an economic perspective, there are two ways to view the impact of carbon accounting on environmental sustainability, which were brought up in the interviews. Firstly, the increased cost of implementing CASs. Monitoring emissions requires the installation and maintenance of measurement equipment and requires data collection and reporting as well. Secondly, the potential cost savings that carbon accounting could lead to through fuel efficiency optimisation and attracting environmentally conscious customers. This is supported by research from Raza and Woxenius (2023), which has shown that environmental performance is positively associated with business performance in shipping companies. Firms that embrace sustainability have a competitive advantage over competitors and can distinguish themselves from rivals (Raza & Woxenius, 2023). Hence, even though implementing CASs can involve upfront expenses, which could lead to higher costs in the short term, carbon accounting can pave the way for better fuel management leading to cost savings in the long run. As the market demand for sustainable products and services grows, it creates market opportunities for shipping companies that would embrace carbon accounting and prioritise environmental responsibility.

Social

Research has shown that there has been a growing societal emphasis on environmental sustainability and this has been driving demand for greener practices across industries (Reichheld et al., 2023). This public sentiment is also evident in the shipping industry, as the industry transitions towards being more environmentally friendly (Hand, 2023). However, the interviewees brought up a potential social hurdle in the form of the affordability of such practices. While society expresses a strong desire for a sustainable future, the question arises of how much people are willing to pay for it. Consumers may be hesitant to absorb significant cost increases that are passed on from businesses that may choose to implement CASs. This gap between caring about the environment and being unwilling to bear additional costs could create a social barrier. If carbon accounting leads to higher prices for goods and services, it might face public resistance, hindering its effectiveness in promoting true environmental sustainability.

Technological

While keeping track of carbon emissions is important for understanding and controlling pollution, the interviewees asserted that relying solely on this method is not enough to make shipping truly environmentally sustainable. Integrating carbon accounting with existing or new operations may require adjustments to address initial challenges and sometimes these challenges can create operational issues that may affect the overall goal of being sustainable. This is evident in the case of hybrid-powered vessels that are meant to reduce fuel usage, but will have other limitations such as reduced range and longer charging times compared to traditional ships, raising questions about overall sustainability (Tan, 2023). Low-carbon fuels or alternative fuels all hold promise for reducing emissions. According to Foretich et al. (2021), each option comes with its own set of challenges such as worldwide availability, infrastructure needs and potential safety risks associated with hydrogen storage and use. Insurance companies will need to assess these risks and adjust premiums accordingly, which will be additional costs for organisations. Thus, there needs to be further development to effectively support large-scale industry transformation. A successful transition requires a combined approach of leveraging carbon accounting for measurements and other practical green technologies to curb carbon emissions.

Environmental

In the shipping industry, the fight against climate change hinges on accurate measurement and targeted action. In this context, the interviewees agreed that carbon accounting is a powerful environmental tool that does not simply provide a total emissions number, but can offer a granular breakdown of an organisation's emissions footprint across different types of machinery. This provides a detailed picture that allows companies

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to move beyond hypothetical estimates and identify specific areas for emission reduction. This is supported by Kaur et al. (2024), who highlight how carbon accounting is a valuable tool for understanding and reducing emissions in examples from various industries. For example, carbon accounting can measure and manage GHG emissions generated throughout the entire lifecycle of a seafood supply chain, including raw material extraction, manufacturing, transportation and disposal (Kaur et al., 2024). It can also facilitate the identification of carbon exposure which sets the stage for the development of carbon management strategies (Kaur et al., 2024). With stricter environmental regulations such as the EU ETS, which will require shipping companies to pay increasing percentages of their emissions from 2025 onwards (Willige, 2024), carbon accounting will allow the shipping industry to proactively prepare for such regulations.

Legal

The legal landscape surrounding GHG emissions is constantly evolving. The IMO's regulatory development over the years and its future objectives show how shipping climate rules have developed since 2011, with targets leading to net-zero emissions by 2050. The interviewees acknowledged that the evolving regulatory landscape makes it important for organisations to have a clear overview of their emissions footprint.

To navigate this evolving legal landscape and avoid potential legal issues, organisations can use carbon accounting to help provide a clear overview of their emissions footprint. This will allow them to assess their compliance with existing regulations set by bodies like the IMO. Gaps can be identified early and corrective measures can be employed to ensure compliance. Furthermore, carbon accounting can position companies favourably for future regulatory changes and even new regulations. From a legal standpoint, having a universal reporting format can make the process smoother as the enforcement may extend to include other stages in the supply chain including manufacturing, storage and transport states.

5 CONCLUSIONS

This section summarises the key findings of the research on implementing carbon accounting in the shipping industry and provides recommendations for future considerations.

5.1 Conclusions

The research explored the feasibility of implementing CASs within the shipping industry to address the growing concern about climate change and its impact. The results showed that pre-service engine testing and standard formulas play a major role in the present approaches to monitoring and controlling carbon emissions. Although these techniques serve as a guide for emission control initiatives, there are issues with accuracy and reflecting actual operational variances.

Several challenges concerning the implementation of CASs were also identified. These challenges include the high cost of compliance, the unclear allocation of cost burdens and the potential loss of sales due to increased transportation expenses. Enforcement issues, negative sentiments and the lack of understanding are also factors hindering the adoption of CASs. However, despite these challenges, the research also identified opportunities and potential benefits associated with CASs, such as transparency and accountability through their standardised approach to measuring and reporting carbon emissions. Moreover, the data produced by CASs assists in guiding the maritime sector towards increased environmental sustainability and compliance with progressively stringent regulations.

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5.2 Implications

Based on the research findings, the following recommendations are proposed to address the challenges and promote the adoption of CASs in the shipping industry. Green financing can play an instrumental role in addressing the cost concerns associated with implementing CASs. Green finance can be defined as "any structured financial activity that has been created to ensure a better environmental outcome. It includes an array of loans, debt mechanisms and investments that are used to encourage the development of green projects or minimise the impact on the climate of more regular projects" (Fleming, 2020). According to research from Wu (2024), green financing is a secure way to promote the adoption of green technology, cut down on carbon emissions and foster sustainable economic development. It does so by helping businesses get funding more easily and encouraging private investors to support environmentally friendly projects. Companies with good environmental practices can potentially qualify for lower interest rates, grants and other financial incentives from institutions promoting sustainability (Wu, 2024). Easier access to affordable financing allows organisations to invest more in eco-friendly technologies. This creates a positive cycle where better environmental practices lead to more resources for further sustainability efforts. Hence, green financing and carbon accounting work hand in hand, benefitting both the company and the environment.

To deal with uncertainty and inaction in the industry as well as address the lack of understanding and resistance to change, regulators and governments have to develop clear and enforceable regulations, recognise the challenges faced by the industry and help with the transition to adopt CASs. Well-defined regulations mandating carbon accounting practices should clearly outline standardised methodologies for data collection and emission calculation. There should also be specific reporting formats to ensure consistency and transparency. To ensure industry compliance, penalties for non-compliance such as fines or port access restrictions can be enacted on vessels that fail to meet carbon accounting requirements. This will remove ambiguity and instil a sense of direction in the industry. Companies will understand the expectations and potential consequences of non-compliance, persuading them to adopt CASs. Regulators and governments have to acknowledge industry challenges, especially recognising the initial costs and potential operational disruptions associated with implementing CASs. They can provide financial incentives to ease the burden which could include grants to assist with the initial implementation costs and tax breaks for companies demonstrating leadership in carbon reduction efforts (Jones, 2023). To deal with the lack of understanding, the IMO can implement training initiatives to equip industry stakeholders with the knowledge and skills necessary to effectively utilise CASs. Training programs that address the technical aspects of CAS operation and data management and the benefits and opportunities associated with carbon accounting practices can be carried out for seafarers, shore-based personnel and other relevant parties. By creating a supportive environment for the shipping industry to embrace carbon accounting, the transition to innovate and adopt greener practices will be smoother and companies will feel more empowered to take the necessary action.

5.3 Limitations and Future Research Areas

This research, however, is subject to several limitations. Firstly, there may be limitations in the scope of the study as it is based on all types of vessels within the industry and not specific to the different types of vessels that exist. This could affect the comprehensiveness of the findings as different vessel types have varying operational profiles, emission outputs and economic considerations. For example, statistics from Statista (2023) showed the estimated worldwide CO_2 emissions from 2020 according to the different ship types. Bulk carriers emitted the most CO_2 at 440 million metric tons, followed by oil tankers at 210 million metric tons, container ships at 140 million metric tons, general cargo ships at 40 million metric tons, offshore vessels and gas carriers at 30 million metric tons and chemical tankers, cruise ships and ferries at 20 million metric tons. This wide range of emission output can be attributed to factors such as the size of the ship, the type of fuel used and deadweight capacity (Boekhoff, 2022), which was not focused on in this study.

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In addition, the study relied solely on interviews with three participants. The experiences and perspectives of only three individuals might not capture the full range of diverse responses associated with carbon accounting and CAS implementation across different shipping companies and vessel types. Using only one research method also limits the ability to triangulate findings and achieve a more comprehensive understanding of the topic. For instance, including a survey alongside interviews could have provided broader data on industry trends and perspectives from a larger group of stakeholders.

Building on the insights gained from this study, future research can delve deeper into specific aspects of carbon accounting in the shipping industry. Some potential areas for development include focusing on specific vessel segments, such as bulk carriers, container ships or tankers to have the research be more tailored to these specificities, which can reveal insights for more targeted solutions and implementation strategies. Additionally, a more comprehensive cost-effectiveness analysis to evaluate the long-term economic benefits of CASs for shipping companies could be conducted. This analysis could consider factors like potential fuel savings, operational efficiencies, access to green financing and potential carbon pricing schemes. By quantifying the cost-effectiveness of CASs, researchers can provide compelling data to encourage wider adoption by demonstrating the long-term financial advantages. Future research could also explore how carbon accounting practices throughout the supply chain might influence logistics, pricing strategies and customer behaviour. This could involve analysing data from shipping companies, freight forwarders and cargo owners to understand the potential ripple effects of implementing CASs across the entire supply chain ecosystem. Pursuing these future research directions will form a more extensive understanding of carbon accounting in the shipping industry and empower organisations to work towards fostering a more sustainable environment.

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Appendix

Guiding Interview Questions

RQ1: Carbon Emissions Measurement and Management

a) Can you share insights into the current techniques and technologies used in the industry to measure and manage carbon emissions throughout entire voyage operations?

b) From your perspective, what are the best practices that should be employed to monitor and control carbon emissions from the beginning to the end of a voyage?

c) Are there any specific challenges or limitations associated with existing methods of measuring and managing carbon emissions in the maritime sector?

RQ2: Challenges and Opportunities in Implementing CASs in the Alternative Fuel Sector

a) In your experience, what challenges do organisations face when implementing carbon accounting systems in the alternative fuel sector?

b) Are there specific opportunities or advantages that arise from adopting carbon accounting systems within the alternative fuel industry?

c) How have you seen the industry respond to the integration of carbon accounting systems, and what lessons have been learned from these implementations?

RQ3: Potential Impact of Carbon Accounting on Environmental Sustainability

a) From your perspective, how do carbon accounting systems contribute to an organisation's commitment to reducing carbon emissions and ensuring long-term environmental sustainability?

b) Can you share examples or case studies where the implementation of carbon accounting systems has positively impacted an organisation's environmental sustainability goals?

c) Are there any potential drawbacks or challenges associated with relying on carbon accounting systems as a means to achieve environmental sustainability goals?

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