PROJECT REPORT

BLOCKCHAIN ENABLED CARBON CREDIT SYSTEM FOR GREEN SHIPPING

Submitted to the School of Maritime Management, Indian Maritime University, in partial fulfilment for the requirements for the award of degree in MBA- Port and Shipping Management

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DECLARATION

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CERTIFICATE

This is to certify that the project report entitled '**Blockchain Enabled Carbon Credit System for Green Shipping'** submitted to School of Maritime Management , Indian Maritime University, Chennai Campus, in partial fulfilment for the award of the degree of Master of Business Administration (MBA) in Port and Shipping Management , is a record work carried out entirely by **Abel P T**, Reg.No. **2303304001.**

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Abel P T

ABSTRACT

The maritime industry, a cornerstone of global trade, is simultaneously a significant contributor to greenhouse gas (GHG) emissions, accounting for approximately 3% of global CO_2 emissions. With international trade projected to expand, emissions from shipping are expected to rise drastically by 2050, intensifying environmental concerns. Despite the introduction of international regulations, current emissions monitoring and carbon credit systems remain fragmented, opaque, and susceptible to fraud and inefficiency. This project explores the application of blockchain technology as a transformative solution to enhance the credibility, efficiency, and transparency of carbon credit systems in the shipping sector.

The study designs and proposes a blockchain-enabled platform for tracking maritime emissions and facilitating real-time carbon credit exchange. Using permissioned blockchain and smart contracts, the system aims to ensure verifiable, tamper-proof records of emission data. This architecture significantly reduces the risk of data manipulation and double counting while enabling automated compliance checks. The integration of Internet of Things (IoT) devices allows for real-time data collection, enhancing the accuracy of emissions reporting and enabling dynamic pricing and trading of carbon credits.

A practical implementation model is proposed through a five-phase deployment strategy, encompassing regulatory framework design, technological infrastructure, stakeholder engagement, pilot testing, and continuous improvement. Furthermore, the system promotes environmentally responsible behaviour among maritime stakeholders by creating financial incentives for emission reductions.

The project also analyses the economic, regulatory, and technological challenges of the existing carbon market and outlines how blockchain can address these issues. With its ability to improve trust, streamline processes, and support cross-border regulatory cooperation, the proposed blockchain-based carbon credit system represents a scalable and effective model for green shipping. Ultimately, this study offers a forward-looking solution aligned with global decarbonization goals and the digital transformation of the maritime sector.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AI	Artificial Intelligence
AIS	Automatic Identification System
API	Application Programming Interface
BC	Blockchain
BC-ETS-RT	Blockchain Emission Trading System Real-Time
BMSCS	Blockchain-Based Maritime Supply Chain system
BOL	Bill of Lading
CII	Carbon Intensity Index
DLT	Decentralized Ledger Technology
DNA	Deoxyribonucleic Acid
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
ETS	Emission Trading Scheme
EU	European Union
EU-ETS	European Union-Emission Trading Scheme
EVM	Ethereum Virtual Machine
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
IMO	International Maritime Organization
IoT	Internet of Things
JIT	Just in Time
KPI	Key Performance Indicator
LNG	Liquified Natural Gas
MARPOL	Maritime Pollution
MBM	Market Based System
MRV	Monitoring, Reportin and Verification
NFT	Non-Fungible Token
NGO	Non-Governmental Organization
P2P	Peer to Peer
SCM	Supply Chain Management
SEEMP	Ship Energy Efficiency Management Plan
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER I
INTRODUCTION

1.1 Background of the Study

The shipping industry is widely recognized as the backbone of global trade, serving as the primary conduit for the movement of goods across continents and connecting diverse economies. Today, approximately 80% of global trade by volume and over 70% by value is carried by sea. This dominance is largely due to the revolutionary advent of containerization in the mid-20th century, which standardized cargo handling, reduced transit times, and significantly lowered shipping costs. As a result, ports around the world have evolved into complex, highly efficient hubs that leverage advanced logistics and information technology systems to manage immense cargo volumes, thereby ensuring the smooth functioning of global supply chains.

Historically, the maritime sector has continuously evolved in response to technological advancements and economic pressures. From the age of sail to the modern era of mega container ships, innovations have consistently aimed at improving operational efficiency and reducing costs. However, these technological leaps have also brought environmental challenges that were not foreseen during earlier periods of industrial growth. As global trade expanded, so did the energy requirements of ships, and with these requirements came an increased dependency on fossil fuels, which has had significant environmental repercussions.

Despite its critical role in supporting economic development, maritime transport is a major contributor to global environmental degradation. The sector is responsible for about 3% of global carbon dioxide (CO_2) emissions—a figure that is projected to increase substantially in the coming decades (table1.1) . Various studies suggest that without decisive intervention; shipping emissions could rise by 50-250% by 2050. This surge is not solely limited to CO_2; ships also emit substantial quantities of nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter. These pollutants contribute to a host of environmental problems, including air pollution, acid rain, and adverse impacts on human health. The emissions have been linked to respiratory ailments in coastal populations, deteriorating air quality, and the degradation of marine and coastal ecosystems.

In addition to airborne pollutants, the environmental footprint of shipping extends to the risks associated with oil spills, improper ballast water discharge, and shipbreaking practices. Oil spills, though infrequent, can have catastrophic impacts on marine life and local economies dependent on fishing and tourism. Ballast water discharge, if not properly treated, introduces invasive species into non-native ecosystems, disrupting local biodiversity. Shipbreaking, often carried out in developing countries with lax environmental regulations, poses severe risks by releasing hazardous materials into the environment during the dismantling process.

To mitigate these environmental impacts, international regulatory bodies have implemented a series of initiatives and stringent standards. The International Maritime Organization (IMO) has been at the forefront of this regulatory transformation. Key frameworks such as MARPOL Annex VI aim to limit emissions of SO_x and NO_x, while the IMO's 2020 sulphur cap, which mandates the use of low-sulphur fuels, represents a significant milestone in reducing air pollution from ships. In parallel, the Energy Efficiency Design Index (EEDI) and the Carbon Intensity Indicator (CII) have been introduced to incentivize the construction of more fuel-efficient ships and to promote operational measures that reduce carbon footprints. Furthermore, market-based mechanisms, such as the European Union Emissions Trading System (EU ETS), have been designed to impose financial accountability on high-emission vessels, encouraging the adoption of greener technologies and operational practices.

Amid these regulatory and environmental challenges, the digital revolution is providing new opportunities for transforming traditional maritime practices. One of the most promising innovations is blockchain technology—a decentralized, distributed ledger that ensures data integrity through its immutable and transparent nature. Blockchain's potential lies in its ability to provide a secure, tamper-proof method for recording and verifying transactions, which can be a game-changer for industries plagued by inefficiencies and lack of transparency.

In the context of the shipping industry, blockchain technology offers a robust framework for enhancing the monitoring and reporting of emissions data. Current systems for tracking carbon emissions are often fragmented and prone to errors, discrepancies, and even manipulation. With a blockchain-based system, every transaction and data entry are recorded chronologically and permanently, ensuring that emissions data is accurate and verifiable. This level of transparency is critical for regulatory bodies tasked with enforcing international environmental standards, as it minimizes the risk of data tampering and fraud.

Furthermore, blockchain has the potential to streamline the carbon credit trading process—a system that has historically been criticized for its inefficiencies and vulnerabilities. The carbon credit market is complex and often fragmented, with multiple intermediaries involved in the verification and trading processes. This complexity not only leads to delays and higher costs but also increases the risk of fraudulent activities, such as double counting of credits or the issuance of non-genuine credits. By integrating blockchain into this system, every carbon credit transaction can be tracked in real time, ensuring that credits are issued, transferred, and retired in a transparent manner. This not only boosts confidence among stakeholders but also encourages greater participation in carbon markets, thereby driving further environmental benefits.

The convergence of blockchain technology with maritime sustainability initiatives also opens up new avenues for cross-border regulatory cooperation. Given the global nature of shipping, a unified digital system for emissions tracking could facilitate smoother collaboration between different regulatory agencies and stakeholders across various jurisdictions. This, in turn, would enhance the effectiveness of international agreements aimed at reducing the environmental impact of shipping operations.

Moreover, the application of blockchain extends beyond compliance and reporting. It can also support innovative business models that promote sustainability. For instance, blockchain platforms can be used to develop decentralized marketplaces for trading carbon credits, where pricing is determined by transparent market dynamics rather than opaque, centralized authorities. Such platforms not only democratize access to carbon markets but also drive the development of new financial instruments that can fund green shipping initiatives.

In summary, the background of this study encapsulates the evolution of the shipping industry as a critical pillar of global trade, alongside the environmental challenges it faces due to increased emissions and other ecological risks. With stringent regulatory measures being implemented worldwide and the continuous rise in global trade volumes, there is an urgent need for innovative solutions to address these challenges. Blockchain technology emerges as a promising candidate, offering unparalleled transparency, security, and efficiency in emissions monitoring and carbon credit trading. This study aims to explore these intersections, providing insights into how blockchain can revolutionize the maritime sector by enhancing environmental compliance and promoting sustainable practices in shipping.

1.2 Problem Statement

The shipping industry is one of the contributors to global greenhouse gas (GHG) emissions, significantly impacting climate change. Despite international regulations and ongoing decarbonization efforts, the sector's heavy reliance on fossil fuels and the persistent use of outdated emission monitoring systems continue to hinder meaningful progress toward sustainability. Traditional carbon accounting methods are fraught with challenges—chief among them being a pronounced lack of transparency and frequent discrepancies in reported data. This not only creates confusion among stakeholders but also impedes the implementation of effective environmental policies.

One of the primary challenges within the current carbon credit system is its inherent susceptibility to fraud and misreporting. In many cases, carbon credits are traded in complex and fragmented markets that lack a centralized oversight mechanism. This fragmentation complicates the verification and validation processes necessary for ensuring that each credit corresponds to a genuine reduction in emissions. As a result, there is a significant risk of double counting or the issuance of credits based on inaccurate or manipulated data. Such inconsistencies undermine confidence in carbon markets and impede efforts to use these credits as a reliable tool for environmental regulation.

The problem is compounded by the lack of real-time data sharing between the various stakeholders involved—shipping companies, regulatory authorities, and carbon market participants. The delays in data reporting and the asynchronous nature of current record-keeping practices contribute to inaccuracies in emissions tracking. In many cases, the information that regulators rely on is outdated or incomplete, leading to increased compliance costs for shipping companies and making it more challenging to enforce environmental standards effectively. This inefficiency is particularly concerning given that timely data is critical for both tracking progress toward emission reduction targets and for the rapid implementation of corrective measures.

Furthermore, regulatory bodies themselves face significant hurdles in enforcing compliance due to the limitations of traditional record-keeping mechanisms.

Paper-based systems and legacy digital platforms are often prone to errors and are vulnerable to tampering. The lack of a unified, standardized approach to data management means that discrepancies can easily slip through the cracks, allowing non-compliant operators to evade penalties. These loopholes not only dilute the impact of regulatory measures but also create an uneven playing field, where companies that invest in cleaner technologies are at a competitive disadvantage compared to those that exploit these system weaknesses.

The cumulative effect of these issues is a carbon credit system that is inefficient, opaque, and prone to misuse—factors that significantly undermine the effectiveness of international decarbonization policies. Without reliable data and a robust mechanism for verifying emission reductions, the shipping industry's contribution to global GHG emissions may continue to grow unchecked, exacerbating climate change and its associated risks.

Blockchain technology presents a viable solution to these multifaceted challenges by offering a decentralized, immutable, and transparent system for emissions tracking and carbon credit trading. Unlike traditional systems, a blockchain-based platform ensures that every transaction and data entry is recorded in real time on a tamper-proof ledger. This level of transparency minimizes the risk of data manipulation and provides a verifiable audit trail that can be accessed by all stakeholders. By ensuring the integrity of emissions data, blockchain technology can dramatically improve the accuracy of carbon accounting processes.

Moreover, the adoption of blockchain can streamline regulatory enforcement by automating compliance verification and reducing the administrative burden associated with traditional monitoring systems. Smart contracts, for example, can be used to automatically trigger penalties or corrective actions when emissions exceed predefined thresholds. This automated approach not only enhances efficiency but also ensures that enforcement is consistent and objective across the board.

By addressing these critical inefficiencies in emissions monitoring and the carbon credit system, blockchain technology holds the promise of significantly enhancing regulatory compliance in the maritime sector. This study, therefore, explores how the integration of blockchain can transform carbon accounting practices, eliminate fraudulent activities, and foster a more transparent and effective regulatory environment in the shipping industry.

Table 1.1: Shipping Emission estimation (*projected)

Year	Estimation(MMT)	Notes
2020	**~806**	≈4% below 2019
2021	**~832**	rebound begins
2022	**~858**	OECD estimate
2023	**~900 ***	up further
2024	**~920 ***	prelim. projected

source: OECD

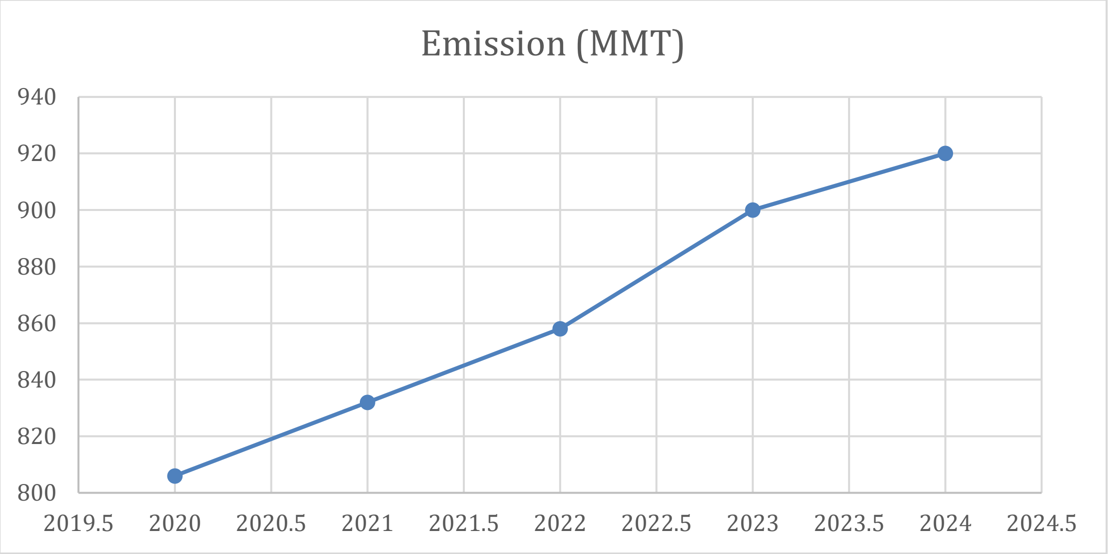

Fig 1.1: Shipping Emission Estimation (from table 1.1)

1.3 Objectives

Objective 1: Develop a Blockchain Platform to Track and Record Maritime Carbon Emissions

The first objective is to design and implement a blockchain-based platform specifically tailored for the maritime industry to track and record carbon emissions. This platform will serve as a decentralized ledger that securely stores emissions data from ships in real time. The goal is to create an immutable, transparent record that minimizes the potential for data manipulation and ensures accuracy. The development process will involve integrating data from shipboard sensors, port monitoring systems, and other relevant IoT devices. In doing so, the platform will not only aggregate emissions data from diverse sources but also standardize the reporting process, making it easier for stakeholders to compare and analyze performance across fleets. By developing such a platform, the study aims to set a technological benchmark for how digital innovations can bring precision and accountability to environmental data management in maritime operations.

Objective 2: Enhance the Regulatory Mechanism and Compliance Regarding Carbon Emissions

The second objective focuses on reinforcing existing regulatory frameworks and compliance mechanisms through the adoption of blockchain technology. Traditional record-keeping and monitoring systems have often fallen short in delivering real-time, reliable data, thereby hampering enforcement efforts. By leveraging blockchain, regulators can access a unified, immutable record of emissions data, which streamlines auditing and oversight processes. This objective includes exploring how smart contracts can be integrated to automate compliance checks and trigger enforcement actions when emission thresholds are exceeded. In addition, the study will assess the feasibility of cross-border regulatory collaboration via shared digital platforms, enhancing the overall robustness of environmental governance. The ultimate aim is to reduce administrative burdens, improve the accuracy of compliance reporting, and ensure that both national and international regulatory bodies can enforce environmental standards more effectively.

Objective 3: Encourage Environmentally Friendly Shipping Practices Through a Verifiable Carbon Credit System

The third objective is centred on creating and promoting a verifiable carbon credit system that rewards shipping companies for reducing their carbon footprint. In the current market, carbon credits often face issues such as fraud and double counting, which undermine their credibility and effectiveness as incentives for environmental performance. This study aims to design a system where every carbon credit is backed by verifiable, real-time emissions data recorded on the blockchain. By ensuring transparency and traceability, the system will build trust among all market participants—including shipping companies, investors, and regulatory authorities. Moreover, the platform will facilitate the secure trading of carbon credits, thereby creating an economic incentive for companies to adopt greener practices. The objective is not only to encourage individual companies to invest in sustainable technologies but also to foster a competitive environment where environmental responsibility becomes a key factor in business operations.

Objective 4: Suggest Measures to Reduce Global Carbon Emissions by Facilitating Real-Time Carbon Credit Exchange

The fourth objective aims to develop and recommend actionable measures for reducing global carbon emissions by leveraging the capabilities of real-time carbon credit exchanges. By integrating blockchain technology, the study envisions a dynamic marketplace where carbon credits can be exchanged instantaneously. This real-time capability allows for rapid adjustments based on the current emissions profile of shipping operations, enabling companies to immediately benefit from reductions in emissions. The objective involves analyzing the potential economic and environmental impacts of such a system, and formulating guidelines for its effective implementation within the global regulatory framework. Additionally, the study will explore how this model can be scaled and adapted to other sectors, creating a blueprint for broader environmental and economic reform. The ultimate goal is to offer a comprehensive set of measures and policy recommendations that facilitate a more responsive, efficient, and transparent carbon market, thereby contributing to the global effort to combat climate change.

1.4 Significance of the Study

The significance of this study extends to multiple stakeholders, particularly shipping regulators and environmental organizations, as it explores the integration of blockchain technology into the carbon credit system. In today's global economy, the shipping industry plays a critical role in facilitating international trade, yet it also contributes substantially to greenhouse gas (GHG) emissions and environmental degradation. The effectiveness of current carbon credit mechanisms is often hindered by issues such as lack of transparency, inefficiencies in tracking emissions, and susceptibility to fraudulent activities. These deficiencies not only compromise the credibility of carbon markets but also impede progress toward global decarbonization targets. This study, therefore, highlights how blockchain technology can be harnessed to address these challenges, thereby strengthening regulatory frameworks, enhancing market integrity, and ultimately contributing to more sustainable shipping practices.

For shipping regulators, the adoption of blockchain presents a transformative opportunity to improve oversight and enforcement of emissions regulations. A decentralized and immutable ledger provided by blockchain ensures that emissions data is recorded accurately and in real time. This transparency is crucial, as it minimizes discrepancies and the potential manipulation of data that often plague traditional record-keeping systems. Regulators can leverage blockchain technology to automate compliance verification processes using smart contracts that trigger predefined actions if emission thresholds are exceeded. This automation reduces the administrative burden on regulatory bodies, enabling more efficient auditing and timely intervention when violations occur. Furthermore, a blockchain-based system facilitates enhanced cross-border cooperation in emission control areas (ECAs), allowing regulatory agencies from different jurisdictions to share reliable data seamlessly. Such cooperation is essential for enforcing international agreements like the International Maritime Organization's (IMO) greenhouse gas (GHG) strategy and the European Union Emissions Trading System (ETS), ensuring that emission reduction commitments are met consistently across global shipping operations.

For environmental organizations, blockchain technology offers significant advantages by enhancing the transparency and traceability of carbon offset initiatives. One of the major criticisms of current carbon credit systems is the risk of double counting and the issuance of fraudulent credits. Blockchain's tamper-proof ledger records every transaction in a transparent manner, ensuring that each carbon credit corresponds to a verifiable reduction in emissions. This level of accountability reassures environmental groups that the credits being traded are genuine, thereby increasing confidence in the market's ability to support meaningful decarbonization efforts. Additionally, blockchain-based platforms empower environmental advocates by providing them with real-time access to emissions data and transaction histories. Such access allows for continuous monitoring of industry compliance and offers a data-driven basis for assessing the effectiveness of decarbonization policies. Consequently, environmental organizations can use these insights to promote more sustainable shipping practices and advocate for stricter environmental standards.

The integration of blockchain into the carbon credit system also holds promise for broader economic and operational benefits. By streamlining the verification and reporting processes, blockchain can reduce compliance costs for shipping companies. Lower administrative costs not only make it easier for companies to meet regulatory requirements but also encourage investment in cleaner technologies. This financial incentive can accelerate the adoption of green shipping practices, as companies are more likely to invest in sustainability initiatives when they are supported by efficient and transparent systems. Furthermore, a more reliable carbon credit system can attract greater participation from both private and public sectors, thereby expanding the market for carbon credits and enhancing its overall impact on reducing global GHG emissions.

Moreover, the implementation of blockchain technology in this context serves as a catalyst for innovation in digital governance. By demonstrating the practical benefits of decentralized systems in a complex, real-world setting, this study can pave the way for further applications of blockchain in other environmentally sensitive industries. The lessons learned from integrating blockchain in maritime emissions tracking could inform similar initiatives in sectors such as energy, agriculture, and manufacturing, where transparency and real-time data are equally critical for regulatory compliance and environmental stewardship.

In summary, this study contributes significantly to the broader goal of reducing the maritime sector's carbon footprint while ensuring that regulatory and environmental objectives are met both efficiently and transparently. For shipping regulators, blockchain offers a tool to overhaul outdated compliance mechanisms, ensuring that emissions data is both accurate and verifiable, and paving the way for more robust international cooperation in enforcing environmental standards. For environmental organizations, the technology promises to restore confidence in carbon markets by eliminating fraud and ensuring that every traded credit represents a true reduction in emissions. The combined effect of these advancements not only strengthens the regulatory framework governing the shipping industry but also drives the sector toward a more sustainable future.

By addressing these critical concerns through the integration of blockchain technology, this study lays the foundation for a transformative approach to carbon management in the maritime industry—one that balances economic growth with environmental responsibility and regulatory integrity.

1.5 Chapter Outline

This chapter outline provides a clear and structured framework for studying the use of block chain technology in the shipping industry, with an emphasis on sustainability. Each chapter is designed to build on the previous one, covering key aspects such as background context, relevant literature, system design, data analysis, and overall conclusions.

- **Chapter 1:** Introduction – Provides an overview of the research, including background, problem statement, objectives, scope, methodology, and significance.
- **Chapter 2:** Literature Review – Examines existing studies on blockchain applications in shipping and sustainability initiatives.
- **Chapter 3:** System Architecture and Implementation – Designing the system and implementation strategies.
- **Chapter 4:** Analysis and Findings – Presents the data, case studies, and discussions on blockchain's role in green shipping.
- **Chapter 5:** Conclusion and Recommendations – Summarizes key findings and provides recommendations for future implementation.

CHAPTER II
REVIEW OF LITERATURE

2.1 Introduction to the Literature Review

The literature review chapter provides a comprehensive examination of existing research related to the application of blockchain technology in the shipping industry, with a particular emphasis on sustainability initiatives. It explores key themes, trends, and findings from scholarly articles, industry reports, and case studies to understand how blockchain has been utilised to address challenges such as transparency, traceability, and environmental impact. This review helps to identify knowledge gaps, highlight successful implementations, and establish the theoretical foundation for the current study.

2.2 Blockchain in the Maritime Industry

The concept of blockchain originates from the field of cryptography, primarily developed to ensure data security and integrity. As the name suggests, blockchain is composed of "blocks" that store data and are cryptographically linked in a linear chain. Each block functions as a digital ledger, and once the storage capacity of a block is filled, it links to the next block, creating a continuous, immutable chain. One of the fundamental attributes of blockchain technology is decentralization, where no central authority governs the network. This decentralization increases trust in the system, as all participants hold a copy of the ledger. Additionally, blockchain is transparent—every user has access to view the transaction history—and immutable, meaning data once recorded cannot be altered or erased. These features are protected through cryptographic algorithms that secure each block and transaction.

Blockchain has evolved significantly beyond its initial implementation in digital currencies like Bitcoin. A notable advancement is the introduction of smart contracts, especially with the development of the Ethereum network. Smart contracts are self-executing agreements where the terms are written in code and automatically enforced when pre-set conditions are met. This innovation adds a new layer of utility to blockchain technology, extending its applications into various sectors, including the maritime industry.

In the maritime sector, blockchain technology is gaining traction as a tool to enhance efficiency, reduce paperwork, and promote sustainability. According to

(Czachorowski et al., 2019)[1], the maritime industry is gradually showing a willingness to adopt blockchain technology. Their study explores real-world use cases, particularly focusing on the Smart Bill of Lading (BOL), a digital version of the traditional shipping document. Traditionally, the BOL requires multiple physical copies and manual verifications, which is time-consuming and error-prone. Smart BOLs, enabled by blockchain and smart contracts, streamline this process by digitizing and automating the documentation, thus significantly reducing delays and administrative costs.

One of the notable platforms working in this domain is CargoX, which has developed a blockchain-based solution for digital BOLs using smart contracts. The platform is community-driven, embracing the decentralized spirit of blockchain technology. It even launched initiatives like the Bug Bounty Program, where individuals are rewarded for identifying system vulnerabilities, thereby improving security and resilience. However, as (Green Edward W Carr et al., 2020)[2] highlight, while blockchain systems are inherently regulation-free, smart contracts may require a governing framework to resolve disputes and ensure legal compliance. This indicates a need for hybrid approaches where decentralized technologies operate within regulated environments.

Another benefit of blockchain, emphasized by (Pu, 2022)[3], is its potential to support environmental sustainability. By reducing the need for paper-based documentation, blockchain adoption in shipping operations contributes to lowering the industry's carbon footprint. Digital transformation in documentation not only enhances operational speed but also aligns with global efforts toward greener logistics and climate goals.

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[1] Czachorowski, K., Solesvik, M., & Kondratenko, Y. (2019). The application of blockchain technology in the maritime industry. In *Studies in Systems, Decision and Control* (Vol. 171, pp. 561–577). Springer International Publishing. https://doi.org/10.1007/978-3-030-00253-4_24

[2] Green Edward W Carr, E. H., Winebrake, J. J., & Corbett, J. J. (2020). *Blockchain Technology and Maritime Shipping: An Exploration of Use Cases in the U.S. Maritime Transportation Sector*.

[3] Pu, S. (2022). *Blockchain adoption in the maritime industry*. https://doi.org/10.32657/10356/158470

2.3 Blockchain and Emission Trading Scheme (ETS)

Currently, Emission Trading Systems (ETS) are primarily regulated and administered by centralized authorities. These regulatory bodies are responsible for issuing, validating, and monitoring carbon credits and emission allowances. However, as previously discussed, the very nature of contracts—especially those with monetary or environmental consequences—requires a regulatory framework to ensure accountability and compliance. With the advancement of blockchain technology, particularly smart contracts, there is a viable opportunity to reduce the administrative overhead traditionally required for such regulation. Smart contracts are self-executing and automatically enforce compliance once conditions are met, minimizing the need for human intervention. As (W. Li et al., 2021)[4] highlight, the integration of blockchain can result in a self-sustaining decentralized market for emissions trading, reducing transaction costs and increasing transparency across all stakeholders.

The potential of blockchain-enabled ETS extends beyond just tracking emissions from ship voyages. It also opens new pathways to include emissions from other parts of the maritime value chain, such as shipbuilding, maintenance, and ship-breaking activities, thereby broadening the scope of environmental accountability. This reflects a more holistic, supply chain–oriented approach to carbon tracking within the maritime sector (Chen, 2022)[5].

A major challenge in current emissions tracking systems is the manual collection of data, which is labour-intensive, error-prone, and inefficient. This inefficiency can be mitigated by integrating Internet of Things (IoT) devices for automated, real-time data collection. (Freire et al., 2022)[6] propose a system combining low-cost IoT sensors with blockchain to securely monitor and store emissions data. The data can then be fed into platforms such as the Blockchain-Based Maritime Supply Chain System (BMSCS). This system allows relevant data to be shared among various stakeholders—regulators, shipowners, and logistics operators—creating a unified, tamper-proof record that enhances both trust and traceability.

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[4] Li, W., Wang, L., Li, Y., & Liu, B. (2021). A blockchain-based emissions trading system for the road transport sector: policy design and evaluation. *Climate Policy*, *21*(3), 337–352. https://doi.org/10.1080/14693062.2020.1851641

[5] Chen, S. (2022). *Blockchain Mechanism for Tracking GHG Emissions through Supply Chain*. https://ssrn.com/abstract=4082449

[6] Freire, W. P., Melo, W. S., do Nascimento, V. D., Nascimento, P. R. M., & de Sá, A. O. (2022). Towards a Secure and Scalable Maritime Monitoring System Using Blockchain and Low-Cost IoT Technology. *Sensors*, *22*(13). https://doi.org/10.3390/s22134895

Another promising application of blockchain in ETS is the tokenization of carbon credits. Tokens can represent measurable units of emissions or savings and be traded on blockchain platforms. Such token-based systems have already been tested in sectors like manufacturing and construction, and maritime is following suit. For example, the company 300Cubits created tradable tokens linked to shipping contracts. These tokens, once used or "burned," are removed from circulation to prevent reuse, creating a deflationary model of accountability (Liu et al., 2023)[7].

Furthermore, non-fungible tokens (NFTs)—which are unique and immutable—have recently emerged as a popular method for managing carbon credits. NFTs allow for transparent ownership tracking and one-time usage of credits. According to(Jenkins et al., 2024)[8], a practical system could involve using IoT sensors to collect emissions data, store it first in SQL databases for preliminary analysis, then transfer the validated data to blockchain ledgers, and finally issue NFTs as carbon credits. These credits can then be tracked, audited, and traded on decentralized platforms.

One of the most advanced implementations is a near real-time carbon accounting framework developed for maritime shipping, as outlined by (Z. Li et al., 2024)[9]. This system leverages Automatic Identification System (AIS) data and fuel consumption metrics to track emissions at 15-minute intervals. The data is stored and analysed, and corresponding carbon tokens are burned in real-time to reflect usage, ensuring integrity and continuous accountability in maritime emissions.

In summary, blockchain technology—when integrated with smart contracts, IoT, and data analytics—offers a transformative approach to ETS in the maritime industry. It promises greater efficiency, transparency, and scalability, reducing the reliance on centralized regulation while enabling near real-time, verifiable, and automated carbon tracking and trading mechanisms. These advancements represent a significant step toward a digitally enabled and sustainable maritime future.

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[7] Liu, J., Zhang, H., & Zhen, L. (2023). Blockchain technology in maritime supply chains: applications, architecture and challenges. *International Journal of Production Research*, *61*(11), 3547–3563. https://doi.org/10.1080/00207543.2021.1930239

[8] Jenkins, J. G., Negangard, E. M., & Sheldon, M. D. (2024). Using Blockchain, Non-Fungible Tokens, and Smart Contracts to Track and Report Greenhouse Gas Emissions. The Accounting Review, 1–29. https://doi.org/10.2308/TAR-2023-0222

[9] Li, Z., Fei, J., Du, Y., Ong, K. L., & Arisian, S. (2024). A near real-time carbon accounting framework for the decarbonization of maritime transport. *Transportation Research Part E: Logistics and Transportation Review*, *191*. https://doi.org/10.1016/j.tre.2024.103724

2.4 Carbon Market Regulation

The European Union Emissions Trading Scheme (EU-ETS), one of the earliest and most prominent carbon markets, provides valuable insights into the strengths and shortcomings of current Emission Trading Systems (ETS). Initially, the EU-ETS focused primarily on carbon dioxide (CO_2) emissions while excluding other potent greenhouse gases and several high-polluting industries. This limited scope, coupled with vague guidelines and policy loopholes, led to instances of overallocation—where too many emission allowances were issued. This over-supply diminished the value of carbon credits and diluted the effectiveness of the system. Ultimately, the burden of excess credits was unfairly shifted across the market, undermining incentives for actual emission reductions (Clò, 2009)[10].

Moreover, emissions trading systems vary significantly in terms of enforcement mechanisms. Some operate on a voluntary basis while others are compliance-driven. The Kyoto Protocol is an example of a framework that initially relied on voluntary participation. However, its mechanisms were later integrated into national legislation by some countries, thus converting voluntary commitments into binding legal obligations (Aakre & Hovi, 2010)[11]. This distinction plays a crucial role in determining the effectiveness and credibility of ETS programs. Compliance enforcement ensures stricter adherence but may face resistance, especially in politically sensitive environments.

Another proposal that emerged in the regulatory discourse was the idea of establishing a CO_2 Central Bank, mirroring the role of central banks in monetary policy. This concept envisioned a centralized institution responsible for managing carbon credit issuance and ensuring market stability. Although a centralized system can offer better control and security, it also risks bureaucratic inefficiencies. In contrast, blockchain-based decentralized markets offer greater transparency, resistance to tampering, and a self-regulating mechanism—making them less susceptible to administrative failures. Additionally, such systems allow dynamic

[10] Clò, S. (2009). The effectiveness of the EU Emissions Trading Scheme. Climate Policy, 9(3), 227–241. https://doi.org/10.3763/cpol.2008.0518

[11] Aakre, S., & Hovi, J. (2010). Emission trading: Participation enforcement determines the need for compliance enforcement. European Union Politics, 11(3), 427–445. https://doi.org/10.1177/1465116510369265

adjustments of credit supply based on decarbonization progress and policy goals (De Perthuis, 2011)[12].

The Kyoto Protocol, administered by the UNFCCC, laid the groundwork for many of today's carbon markets. However, its implementation was marred by conflicts between developed and developing nations. These geopolitical tensions resulted in uneven commitments and inconsistent enforcement, undermining the protocol's intended impact. As a result, there is now a growing call for a globally unified carbon market—one that ensures international oversight while allowing for regional differentiation to accommodate varying economic and developmental contexts (Cheng, 2022)[13].

Furthermore, the line between voluntary and compliance-driven markets is increasingly blurred, prompting discussions about the need for clearer governance structures. As (Ahonen et al., 2022)[14] suggest, the fragmented nature of current systems requires a comprehensive examination of whether centralized or decentralized governance models are more effective in ensuring market integrity and environmental outcomes.

Carbon markets also hold significant potential for revenue generation. For instance, global carbon markets have already generated approximately $26 billion in revenue, demonstrating their fiscal utility alongside environmental objectives. Comparative studies show that cap-tightening measures improve the efficiency and credibility of ETS programs. The California–Quebec linked system, for example, implemented stricter caps and outperformed other systems. In contrast, the Korean ETS, which relied heavily on free allocation of credits, struggled to create adequate market pressure to reduce emissions (Narassimhan et al., 2018)[15].

In conclusion, while early ETS models such as the EU-ETS revealed critical flaws—such as over-allocation and regulatory vagueness—they also provided a

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[12] de Perthuis, C. (2011). Carbon Markets Regulations: The Case for a CO2 Central Bank. Paris Dauphine University Climate Economics Chair.

[13] Cheng, Y. (2022). Carbon Derivatives-Directed International Supervision Laws and Regulations and Carbon Market Mechanism. Sustainability (Switzerland), 14(23). https://doi.org/10.3390/su142316157

[14] Ahonen, H. M., Kessler, J., Michaelowa, A., Espelage, A., & Hoch, S. (2022). Governance of Fragmented Compliance and Voluntary Carbon Markets Under the Paris Agreement. Politics and Governance, 10(1), 235–245. https://doi.org/10.17645/pag.v10i1.4759

[15] Narassimhan, E., Gallagher, K. S., Koester, S., & Alejo, J. R. (2018). Carbon pricing in practice: a review of existing emissions trading systems. Climate Policy, 18(8), 967–991. https://doi.org/10.1080/14693062.2018.1467827

foundational learning platform. Moving forward, integrating blockchain, clarifying governance structures, and ensuring global coordination will be essential for building robust and effective carbon markets.

2.5 Decarbonization in Maritime

While carbon dioxide remains the primary greenhouse gas contributing to global warming, black carbon—a short-lived climate pollutant—ranks second in its climate impact. Emitted through the incomplete combustion of fossil fuels, black carbon is particularly problematic in the shipping industry. It has a high capacity to absorb sunlight, thus warming the atmosphere and accelerating the melting of polar ice. In the context of maritime emissions, a strategic approach to mitigate black carbon includes installing filter systems and introducing regulatory guidelines for cleaner ship engine manufacturing (Eyring et al., 2010)[16].

The International Maritime Organization (IMO) is the principal regulatory body spearheading global decarbonization efforts in the maritime sector. Its Initial Strategy on GHG Reduction, adopted in 2018, aimed at reducing greenhouse gas (GHG) emissions from ships by at least 50% by 2050 compared to 2008 levels. However, the initial roadmap did not propose implementing an Emission Trading System (ETS) for the maritime industry. Instead, the focus was on operational and technical measures to lower carbon emissions, such as speed optimization and fuel efficiency (Joung et al., 2020)[17]. Nevertheless, the IMO is now exploring market-based mechanisms, including ETS-like frameworks, to accelerate decarbonization.

Despite these efforts, the IMO faces several formidable challenges. One such issue is the lack of research and development (R&D) infrastructure and skilled manpower required to innovate and implement low-carbon technologies. The sector also grapples with the absence of a unified policy framework, which hinders coordinated international action. There is a growing call for a single, comprehensive

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[16] Eyring, V., Isaksen, I. S. A., Berntsen, T., Collins, W. J., Corbett, J. J., Endresen, O., Grainger, R. G., Moldanova, J., Schlager, H., & Stevenson, D. S. (2010). Needs and opportunities to reduce black carbon emissions from maritime shipping. Atmospheric Environment, 44(37), 4735–4771. https://doi.org/10.1016/j.atmosenv.2009.04.059

[17] Joung, T. H., Kang, S. G., Lee, J. K., & Ahn, J. (2020). The IMO initial strategy for reducing Greenhouse Gas(GHG) emissions, and its follow-up actions towards 2050. In Journal of International Maritime Safety, Environmental Affairs, and Shipping (Vol. 4, Issue 1, pp. 1–7). Informa UK Ltd. https://doi.org/10.1080/25725084.2019.1707938

regulatory body or mechanism that ensures consistency and transparency across nations and fleets (Bach & Hansen, 2023)[18].

An early controversy within the IMO's policy debates was whether developing countries should receive preferential treatment in emission regulations. This notion was eventually overturned. The consensus now is that all vessels, regardless of the flag state, must adhere to energy efficiency regulations such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) (Bodansky, 2016)[19]. This global standardization is vital to maintaining fairness and accountability in international shipping.

Beyond IMO strategies, multiple carbon footprint standards have been developed to guide compliance and reporting. Notable examples include ISO 14067 and EN 16258, both of which help in quantifying and managing GHG emissions. However, emissions reduction is a shared responsibility across various maritime stakeholders—ship repair yards, ship owners, operators, charterers, cargo owners, port authorities, and vessel traffic services all play critical roles in ensuring sustainability (Karaś, 2023)[20].

Economic analyses reveal the financial implications of implementing IMO’s decarbonization strategies. The total investment required could reach $1.3 trillion, spanning retrofitting, infrastructure upgrades, and alternative fuel adoption. One such strategy, slow steaming, has already shown measurable success by reducing fuel consumption and, consequently, emissions. However, the industry must also address carbon leakage—the relocation of emissions-intensive operations to regions with lax regulations. To combat this, some regulatory proposals include grading ships based on efficiency, enabling more effective inspections and incentives for cleaner vessels (Park et al., 2024)[21].

While these strategies reflect a genuine commitment to carbon-neutral shipping, the associated costs are substantial. Estimates suggest that compliance with

[18] Bach, H., & Hansen, T. (2023). IMO off course for decarbonisation of shipping? Three challenges for stricter policy. Marine Policy, 147. https://doi.org/10.1016/j.marpol.2022.105379
[19] Bodansky, D. (2016). Regulating greenhouse gas emissions from ships: the role of the international maritime organization. In In Ocean Law Debates. Brill Nijhoff. https://ssrn.com/abstract=2813785
[20] Karaś, A. (2023). An Analysis Of The Carbon Footprint In Maritime Transport: Challenges And Opportunities For Reducing Greenhouse Gas Emissions. TransNav, 17(1), 199–203. https://doi.org/10.12716/1001.17.01.22
[21] Park, S., Lee, H., & Kim, D. (2024). Regulatory compliance and operational efficiency in maritime transport: Strategies and insights. Transport Policy, 155, 161–177. https://doi.org/10.1016/j.tranpol.2024.06.024

IMO regulations could cost around $60 billion annually. Moreover, these environmental measures may come with unintended side effects, such as increased transportation times or operational inefficiencies, which must be addressed through robust planning and technological innovation. Importantly, the rate of adaptation to emission control measures remains slow. Current solutions are largely effective only in the short term, highlighting the need for long-term, systemic transformations within the maritime sector (Serra & Fancello, 2020)[22].

In conclusion, while regulatory progress by the IMO and global standards offer a roadmap for reducing emissions in maritime transport, the path forward requires more aggressive policies, consistent global cooperation, and significant investment to achieve meaningful, long-term decarbonization.

2.6 Verifiable carbon credit system in shipping

Voluntary carbon offset is one of the methods used by the companies to reduce the carbon footprint but there is a major catch. The exist standards are not consistent and nobody has any idea which system is better. And the voluntary system is just an ethical approach. the major element of the carbon market is the accounting standard, monitoring, verification and certification standard and the registration and the enforcement system(Dhanda & Hartman, 2011)[23]. There is also an impact on the LNG fleet which is has reduced the emission compared to the Diesel operated fleets (Franc & Sutto, 2014)[24]. There was also a case for the ethics where companies claimed that they have one shipment completely carbon neutral. They used the LNG ship and then bought the offset to show that they have carbon neutral shipping (Bose et al., 2021)[25].

There are also cost for the use of carbon market which affects the price of the goods. It also depends upon the type of contract for example spot or time

[22] Serra, P., & Fancello, G. (2020). Towards the IMO's GHG goals: A critical overview of the perspectives and challenges of the main options for decarbonizing international shipping. Sustainability (Switzerland), 12(8). https://doi.org/10.3390/su12083220
[23] Dhanda, K. K., & Hartman, L. P. (2011). The Ethics of Carbon Neutrality: A Critical Examination of Voluntary Carbon Offset Providers. *Journal of Business Ethics*, *100*(1), 119–149. https://doi.org/10.1007/s10551-011-0766-4
[24] Franc, P., & Sutto, L. (2014). Impact analysis on shipping lines and European ports of a cap- and-trade system on CO2 emissions in maritime transport. *Maritime Policy and Management*, *41*(1), 61–78. https://doi.org/10.1080/03088839.2013.782440
[25] Bose, A., Cohen, J., Fattouh, B., Johnson, O., & Spilker, G. (2021). *Voluntary markets for carbon offsets: Evolution and lessons for the LNG market*. The Oxford Institute for Energy Studies.

chartering.(Rojon et al., 2021)[26]. This also is a good strategy for the market to since the differentiation make the demand. Like for the charterer require a new vessel which reduces the carbon footprint and the ship owners will get competitive to get the vessel with the lower emission. Which creates the demand for the ship builders to create the ships. And need to consider which method is better from the following such as the offsetting, scheme, emission trading scheme, climate levy. (Kachi et al., 2019)[27].

This is the perfect opportunity for the blockchain to step in because it will be helpful to solve the problem of monitoring, reporting, and verifying (MRV). A common problem encountered in the ETS. It also solves other problems such as double counting and cutting down the cost due the automated process(Basu et al., 2024)[28]. The system gives out the general idea of using smart contracts and minting and the burning of Non-Fungible Token (NFT). And the participants are the generator, consumer and the regulator (Saraji & Borowczak, 2021)[29]. There are blockchain platform for carbon footprints in the market and it solves the trust problem. There are other decentralized ledger technologies(DLT) for which can be used in the market and then the utilization of the IoT and Blockchain to optimize the process(Gupta, 2024)[30]. Which also gives a lot of data that can be utilized and then predictive analysis become much more accessible in the carbon credit system in the maritime sector(Boumaiza & Maher, 2024a)[31].

2.7 Realtime Carbon Credit: Promoting Decarbonization

Offsetting is one of the methods utilized most by the companies in order to promote decarbonization. And this revenue generated from the offsetting is used to fund the renewable energy projects in the developing countries. While it's a good

[26] Rojon, I., Lazarou, N. J., Rehmatulla, N., & Smith, T. (2021). The impacts of carbon pricing on maritime transport costs and their implications for developing economies. *Marine Policy*, *132*. https://doi.org/10.1016/j.marpol.2021.104653

[27] Kachi, A., Mooldijk, S., & Warnecke, C. (2019). *Carbon pricing options for international maritime emissions Carbon pricing options for international maritime emissions Publisher NewClimate-Institute for Climate Policy and Global Sustainability gGmbH*. http://newclimate.org/publications/

[28] Basu, P., Deb, P., & Singh, A. (2024). Blockchain and the carbon credit ecosystem: sustainable management of the supply chain. *Journal of Business Strategy*, *45*(1), 33–40. https://doi.org/10.1108/JBS-09-2022-0157

[29] Saraji, S., & Borowczak, M. (2021). A Blockchain-based Carbon Credit Ecosystem. *ArXiv Preprint ArXiv:2107.00185*.

[30] Gupta, K. (2024). *Carbon Credits and Offsetting: Navigating Legal Frameworks, Innovative Solutions, and Controversies*. www.ijfmr.com

[31] Boumaiza, A., & Maher, K. (2024). Harnessing Blockchain and IoT for Carbon Credit Exchange to Achieve Pollution Reduction Goals. *Energies*, *17*(19). https://doi.org/10.3390/en17194811

project, it is used as a method to greenwashing themselves (Bernstein, 2023)[32]. While promoting carbon neutrality it should also be taken into account that the company stake holders also lose the money since the current carbon neutral or the low carbon m9ethodologies are of higher cost than the traditional ones. Which is also the reason why the emission should be controlled while being investing in the other emission producing fields for example the google uses solar power the office while using the money to invest in the nearby farm which produce CO2 emissions (Leonhard, 2017)[33]. One of the main reasons this is being such an issue is that the consumers and producers care about the cost of the product. It should be cheaper which creates much more value to them. Which in turn uses the cheapest shipping method. Therefore, it uses the fossil fuel. And this continues as a vicious cycle (Priyono, 2023)[34].

Now comes the role of the Realtime carbon credit system where the data is updated in the Realtime. The real time data is also used for the the calculation of other emissions such as the SO_x and the NO_x , which is also another contributor to the GHG. This real time system can also be used to get to much finer emissions and be based on the output of the actual carbon or other emission rather than the input-based models, usage of cutting-edge laser optics is used in this model (Zuo & Niu, 2024)[35].

The real time system cannot be complete without the use of blockchain, smart contracts and the IoT. It is required for a streamlined, transparent and adaptable ecosystem for carbon trading. This also use the data for the pricing since the data is updated in real time (Baklaga, 2024)[36]. While it also solves the problem traceability along with it. Because the credit generation in the current systems are made without actual reduction. The world bank also predicts that the use of blockchain reduces the cost up to 90% (Boumaiza & Maher, 2024)[37]. All together the blockchain is key to the

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[32] Bernstein, A. A. (2023). The Perfect is the Enemy of the Good: Carbon Credits and The Perfect is the Enemy of the Good: Carbon Credits and Funding for Decarbonization in Developing Countries Funding for Decarbonization in Developing Countries. *New England Journal of Public Policy*, *35(2)*. https://scholarworks.umb.edu/nejpp/vol35/iss2/4

[33] Leonhard, R. (2017). FORGET PARIS: BUILDING A CARBON MARKET IN THE U.S. USING BLOCKCHAIN-BASED SMART CONTRACTS. *Available at SSRN 3082450*.

[34] Priyono, F. J. (2023). Trade and Decarbonization: Opportunities and Challenges. *IOP Conference Series: Earth and Environmental Science*, *1270*(1). https://doi.org/10.1088/1755-1315/1270/1/012003

[35] Zuo, Z., & Niu, Y. (2024). Real-time monitoring and control systems for emission compliance in power plants. *Frontiers in Environmental Research*, *2*(2). https://doi.org/10.61784/fer3006

[36] Baklaga, L. (2024). *Synergizing AI and Blockchain: Innovations in Decentralized Carbon Markets for Emission Reduction through Intelligent Carbon Credit Trading*. https://doi.org/10.32996/jcsts

[37] Boumaiza, A., & Maher, K. (2024). Leveraging blockchain technology to enhance transparency and efficiency in carbon trading markets. *International Journal of Electrical Power and Energy Systems*, *162*. https://doi.org/10.1016/j.ijepes.2024.110225

part to direct reduction of the emissions and indirectly green innovation is also key to this (Karmaker et al., 2025)[38]. It should be also noted that the current system of blockchain is without any visual representation which means that the data cannot be easily understood by the stakeholders. This visualization study conducted has given out result that can be also used to detect the fraud and arbitraging. It solves the problem of finding out the arbitrage pattern and also detects the fraud while being and a tool to understand what happening within the system (Tsai, 2025)[39].

[38] Karmaker, S. C., Sen, K. K., Chapman, A. J., Mohiuddin, G., & Saha, B. B. (2025). Innovation under Cap-and-Trade: How emission trading systems propel decarbonization. *Next Energy*, *7*, 100220. https://doi.org/10.1016/j.nxener.2024.100220

[39] Tsai, Y. C. (2025). Enhancing Transparency and Fraud Detection in Carbon Credit Markets Through Blockchain-Based Visualization Techniques. *Electronics (Switzerland)*, *14*(1). https://doi.org/10.3390/electronics14010157

CHAPTER III
SYSTEM DESIGN AND IMPLEMENTATION

3.1 Overview of Blockchain Technology

Blockchain technology is a decentralized and distributed digital ledger system that records transactions across a network of computers in a secure and tamper-proof manner. It operates online and is maintained through a consensus mechanism, where all participating nodes (or partners) agree on the validity of the data being recorded. One of the key features of blockchain is its ability to function without the need for a central governing authority, making it highly transparent and resilient. Each transaction, once verified and added to the chain, becomes immutable, ensuring data integrity and trust among stakeholders. Block chain can be effectively used for securely documenting and transferring digital assets, making it particularly valuable in industries where trust, traceability, and accountability are critical—such as the shipping and logistics sector.

3.1.1 Definition and Functionality

Fundamentally, it is a decentralized and distributed ledger. It is transparent and immutable record of transactions. a peer-to-peer network is used to construct the cryptographic database and it is available to various users. The transaction record is unalterable and it is time stamped and linked to the prior entries. It has ever expanding record and it require validation from all the nodes. New transaction recorded in blocks along with information regarding the last blocks making them interconnected. Proof of work is a concept where the connection to previous block is solved through a cryptographic challenge which is computationally intensive but straight forward. This makes it difficult to manipulate. It has autonomous validation to confirm legitimacy of transactions.

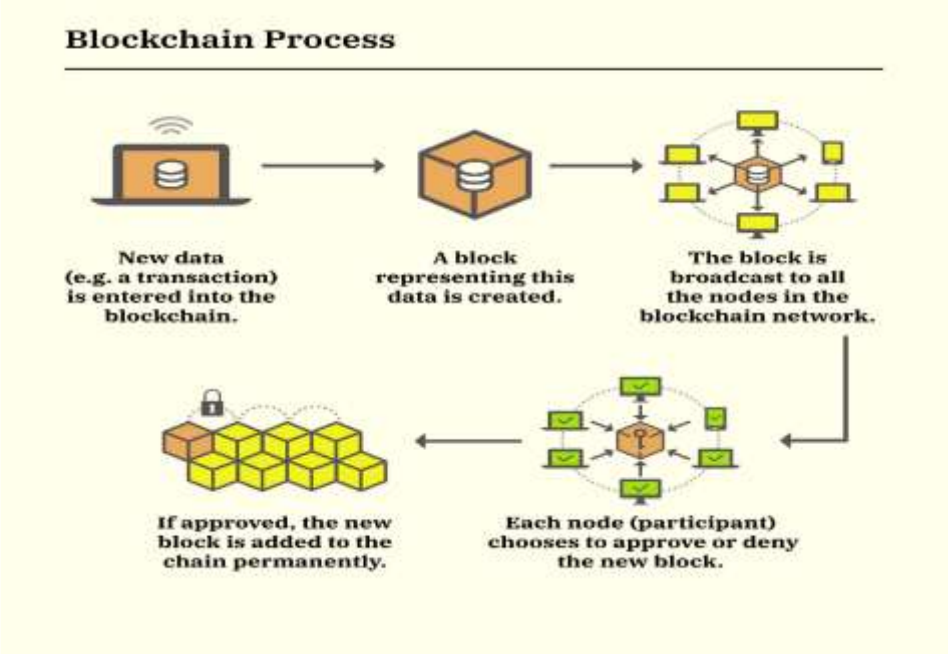


Fig. 3.1: Blockchain process, source: https://money.com/what-is-blockchain/

3.1.2 Principal Characteristics

- **Decentralization**: No single entity has control over the data or it doesn't depend on a centralized authority.
- **Distributed Architecture:** A complete copy can be accessed by the user for an audit any time. The nodes; computers which record, transmit and sync the data in near Realtime.
- **Immutability:** Recorded transactions cannot be altered. Longer blockchains make it challenging to make adjustments.
- **Transparency and Traceability:** Every Transaction is documented and it is unalterable.
- **Security:** Cryptographic guidelines and consensus mechanism to uphold the integrity and consistency of the data.
- **Consensus Mechanism:** Eliminates the need for a Central Authority by reaching a consensus regarding the network's status. Transactions receiving the validation from the nodes in the network.
- **Peer-to-Peer Transactions:** Direct exchange of Value or information without the involvement of intermediaries.

3.1.3 Types of Blockchain

Categorized based on the accessibility as either permissioned or permissionless.

- **Permissioned (Public):** Open to Anyone without any authorization or specific software. Example: Bitcoin, Ethereum, Litecoin.
- **Permissioned (Private/Consortium):** Requires Authorization for participants. Align mor closely with existing regulatory frameworks due to the identification of participants.
    - It has much more flexibility and also it can modify the rules according to the requirement. It can even reverse the transactions, and can be more suitable for business that prioritize privacy, speed, and regulatory compliance.
    - Private BC is controlled by a single entity while consortium is managed by multiple entities. Examples: R3, B3I and EWF

3.1.4 Evolution and Applications

It has evolved from merely an encrypted digital currency to offer much more reliable services. Some of the application comes to the identity management, healthcare, governmental elections, insurance and logistics. In the maritime sector it has much more potential and can be used as an international platform for information exchange, tracking and tracing data, issuing digital certificates, bills of lading, cross border payments and strengthening cybersecurity measures. In the environmental sustainability, it can be used for the carbon trading, it reduces the cost and it provides the transparency and traceability, eliminates the need for the intermediaries which also reduces the efficiency of the process.

3.2 Design of the Carbon Credit System

3.2.1 Objective

Main objective is to reduce the Green House Gas (GHG). A monetary value is given to the carbon pollution, creating a financial incentive for emission reductions. Organizations that emit GHG can pay the monetary value for those who successfully reduce their emissions or those who are producers.

Mitigation of the climate change is one of the key elements where carbon trading offers a financial reward for reducing emissions. A market driven mechanism is a cost-effective strategy for this. The financial incentive is what drives the entities to reduce their carbon emission.(Chen, 2022)[40] It also fosters innovations in the low-carbon technologies because of the need for the reduction of emission and the financial incentives. It supports the transmission to a low carbon economy, where sustainable practices are promoted. It allows for the emission offsetting where the they can convert the emission into monetary value and balancing out through the offsetting of unavoidable emissions. It can be great funding source for the emission reduction initiatives; the sale of carbon credits is a great revenue for the projects in reduction of greenhouse gases(GHGs). It also assists in the achievement of the climate objectives; it aids in the fulfilment of the commitments outlined in the Paris Agreement.

3.2.2 Method of Reducing Fraud.

- **Enhancing Transparency and Traceability:** Whenever a new carbon project is designed it should be provided the comprehensive information regarding their initiatives, including methodologies, monitoring verification processes and performance metrics. Robust tracking system for the carbon credit; origin to application.
- **Implementing Verification and Monitoring:** It is essential to implement this as it confirms the authenticity of the carbon credit. A comprehensive system is required for this and a stringent verification protocol to guarantee the accuracy of the credit generation and the trading preventing inflation. Third party verification can also be implemented to improve the integrity.
- **Double Counting Issue:** Same reduction counted twice reduces the accuracy of the process. Tracking system, and contractual agreement for the organizations in the trading platform to address it. And also, the Efficiency of Project Selection and the Accuracy of the Monitoring. This to prevent the Greenwashing and development of the new methodologies.
- **Enhancing Technological Innovation:** Integrity of the carbo markets is crucial, a unified registry for the carbon credits, the legal and regulatory frameworks can be fortified and a “reverse charge mechanism” to reduce fraud activities.

[40] Chen, S. (2022). *Blockchain Mechanism for Tracking GHG Emissions through Supply Chain*. https://ssrn.com/abstract=4082449

3.2.2.1 Strategies for Mitigating Fraud in the Maritime Industry

The above methods can also be implemented in the Maritime Industry. Such as the improvement of the Transparency and the Traceability. It also requires the digitization of the documents and it enhances the traceability of goods, fuels and documentation. It should also be noted that the data integrity and security should be enhanced through a permissioned blockchain may seem as a solution for this as it has a control over the data and a regulatory body such as the IMO can implement Regulatory Frameworks to collaborate with the Shipping Organizations to Improve it. The cooperation and the collaboration are required from all the participants. By adopting these strategies, the reliability and efficiency of the carbon market and the maritime operations can be significantly improved. It also reduces the fraud and increases the integrity for sustainable practices.

3.2.3 Promoting Green Shipping Practices

- **Regulatory Frameworks:** Rigorous Regulations is a fundamental strategy. IMO has some initial strategy regarding this, where it introduced the energy efficiency of the vessels to mitigate the GHG emissions. It has aimed to reduce the carbon emission in throughout this century. It includes the Existing Vessel Efficiency Index (EEXI). And the Annual Operating Carbon Intensity Indicator (CII) rating and the Enhanced Vessel Efficiency Management Plan (SEEMP) are used to lower carbon intensity. Also, the EU Emission Trading System (ETS) and the Fuel EU Maritime Regulation, contribute to the reduction of emissions.
- **Market-Based Measures (MBMs):** Carbon Taxes, which is steered towards the technological innovation as it is to promote low carbon options rather than having the burden to pay the taxes. ETS is another MBM and it has been deployed for the past few years for multiple sectors. Early adoption incentives, bunker levy, and the incentives and preferential treatment from the ports can also be used in this one.
- **Technological Innovation:** Clean Exhaust gas, heat recovery, waste energy management and utilization of lightweight materials. Development of alternative fuel vessels such as LNG, Biodiesel, hydrogen and ammonia are

vital in this strategy. Solar and wind energy generation and utilization is also an active part this.

- **Enhancement of Operational Activities:** This plays a substantial part in the reduction; slow steaming is one of the major methods where a 10% reduction in speed can result in a 27% decrease in emission as the ships follow the Propulsion law. Weather routing, hull cleaning, systems for optimizing the ship speed, energy management system and the streamlining all of these together can significantly reduce the emissions (Brown, 2024)[41].
- **Port Functions:** Plays a crucial role, use of shore power and the environmentally friendly technologies. Sustainable port development and optimized berthing processes. Preferential treatment to the port for promoting the eco-friendly practices.
- **Economic and Social Influences:** Increase in fuel prices promote the need for the energy efficiency. Awareness and the informed decision of the producers and consumers, promoting the sustainable practices in the shipping industry.
- **Collaborative and Comprehensive Strategies:** A collaboration among the shipping companies, port authorities, government and various stakeholders is a necessity and the strategies include for operational tactics, tech innovations and environmental regulations.

3.2.4 Different Users and Interactions

- **Prosumers and Traditional Consumers (Energy Sector):** Prosumers: Produce their own energy and utilizes them such as use of solar grid and selling back the excess. The traditional consumer can enter the market for a P2P platform and the need for the Intermediary is removed here.
- **Carbon Market Participants:** If a blockchain platform is used then the users will be prosumers, traditional consumers and the other organizations who needs to reduce their carbon emissions. Their interaction will be direct and mostly automated.
- **System Administrator/Regulator:** The Regulatory body needs to create a framework for the regulations and keep the integrity of the system. BC-ETS-RT, in this model the government act as the regulator and the supervisor.

[41] Brown, G. (2024, September 6). Slow steaming, green shipping | Happy Eco News. *Happy Eco News*. https://happyeconews.com/slow-steaming-green-shipping/

- **Platform Users (General):** Allowing third party to the system is also important as this provides to improve the authenticity. These users have access to the platform after the verification and authentication of their identities.
- **Broader Ecosystem Stakeholders:** This consists of the government bodies, regulatory agencies, market participants, energy companies, consumers, retailers, and distributed system operators. They look out for the system's effect on the carbon emission, user satisfactions and economic sustainability and may contribute to regulatory development.
- **Maritime Logistics Participants:** Ship operators, buyers and intermediaries, ports and intermodal operators, shipowners, carries and receivers. They have individual roles to play in the Supply chain and interactions depends upon their need to reduce their carbon footprint.
- **System Integrity Maintainers:** Auditors and Security Researchers are needed to maintaining the integrity of the system. A bug bounty program can be used to find the vulnerabilities in the system.

3.2.4.1 Interactions

The interactions are through the Decentralization; where there will be no centralized authority or a single entity to control the network, Smart Contracts; to automate the process with conditional contracts, Immutable Ledger; it helps to reduce the manipulation of the data, IoT integration; automatically collect and store the data and sent for verification and Hybrid Storage solutions for the large data collections and storage.

3.3 Blockchain Selection and Smart Contract Implementation

3.3.1 Blockchain Selection

The Preferred Blockchain for this carbon credit system for the maritime sector is the permissioned blockchain. The regulatory compliance can be easily maintained since the participants are identified and the transaction reversal is also available for the owners (in private) and by the governing body (in consortium). The privacy is also a major feature that is required for the users and this BC provides the feature making it much more attractive for the users. A consensus mechanism is in place to improve the performance of the system. And it is much easier to scale. It can also be made to specific need and much more control is available for the administrators.

Cost efficiency is much better in the method as the consensus mechanism works much better with lower energy consumptions in response to the proof of work concept where each linking is required with the intense computational energy required. It also supports the use of smart contracts which helps in the automations of the process and enforcing the agreements. Which are much better solutions for the carbon credit system and for the supply chain management.

Hyper ledger fabric provides environment for rapid smart contract development. It is used by the Climate Chain Coalition for carbon trading among member and is a modular platform suitable for permissioned blockchains. VeChainThor powers the VeCarbon platform for tracking and trading carbon credits. Consortium blockchains or hybrids of private and public blockchains like Hyperledger are suggested for emission trading systems in road transport to manage data sensitivity. ShipChain utilizes a public permissionless blockchain (Ethereum) for some transactions and private sidechains of Ethereum for other data in supply chain management.

The Alternative for the Permissioned BC is the Permissionless (Public) BC. Which provides only a few pros compared to the Permissioned BC. it has a transparency and traceability for any users and the Accessibility is also very high since authentication is not required. It also has Digital Assets and Tokenization which is a good method for trading the credits.

Other than this it can been seen that the Public (permissionless) BC cannot be scaled easily due to high volume of users and there is not control over the data. The cost efficiency is low due to the proof of work concept where each block linkage requires high computational power and the energy consumption is very high. The regulatory compliance is also a nightmare when using the Permissionless BC.

3.3.2 Smart Contracts

It is just a computer protocol which can automatically execute the terms of an agreement when predefined conditions are met. It doesn't need the intervention of humans or the third parties. It highly transparent, secure and robust. The blockchain platforms compliment the use of Smart contracts and it works easily in the blockchain networks.

3.3.2.1 Characteristics

- **Automation:** Smart contracts operate automatically once predefined conditions are met. In the maritime context, this could include the automatic calculation and recording of carbon emissions based on ship activity or fuel consumption data. Automation minimizes manual intervention, thereby reducing errors and delays in data processing.
- **Self-Execution:** Smart contracts execute themselves when the terms coded within them are fulfilled. For instance, a carbon credit could be automatically transferred when a shipping line meets its emission reduction target. This ensures compliance with emission norms without the need for manual enforcement.
- **Immutability:** Once data is recorded on the blockchain, it cannot be altered. This immutability ensures that carbon emission records are tamper-proof, trustworthy, and auditable. It enhances the credibility of reporting and discourages fraudulent behavior in emission tracking or credit claiming.
- **Transparency:** All parties involved in a blockchain-based system have access to the same data in real time. This transparency fosters trust among stakeholders such as regulators, shipping companies, and environmental organizations, as it provides a verifiable trail of emission data and smart contract actions.
- **Intermediary Reduction:** Blockchain technology eliminates the need for third-party intermediaries such as brokers or verification agencies, as the trust is embedded in the technology itself. This reduction in intermediaries lowers the costs associated with monitoring and compliance, and speeds up transaction times.
- **Higher Efficiency and Reduced Costs:** By combining automation, self-execution, and intermediary reduction, smart contracts significantly improve operational efficiency. Processes that once required manual verification and approval can now be completed in seconds. This not only saves time but also reduces administrative costs, making emission tracking and credit trading more viable and scalable.

3.3.2.2 Applications

- **Carbon Trading Markets:** Automate the issuance and tracking of carbon credits, enforce compliance, facilitates the seamless trading of assets. Automate the retirement or the burning(voiding) credits. Conditions to avoid double counting.
- **Energy Sector:** If a public user can generate energy the excess can be sold to a smart grid where it will automatically execute the conditions and the monetary transaction can also be done seamlessly. Peer to peer is another method for smart contract without the need for a platform. Only the provider and the consumer are in this contract.
- **Maritime Industry:** Since the Bill of Lading (BOL) is a carriage of contract it can be substitute with the Smart BOL where it facilitates the shipment tracking , and manage payments. It can also hold the payments until the conditions are met.
- **Supply Chain Management (SCM):** Tracking product provenance, and the movement of digital assets. The movement of a product generates the carbon footprint and the Smart contract can track and execute it necessarily.
- **GHG Emission Tracking and Reporting:** The use of NFT (Non-Fungible-Token) can automate the assignment, aggregation and exchange of the emission data across a firm’s value chain creating a reliable provenance of emission for reporting purposes.

3.3.2.3 Blockchain platform for Smart Contract, Benefits and Limitations

- Ethereum: A public, permissionless blockchain widely used for smart contract development with its programming language Solidity and the Ethereum Virtual Machine (EVM).
- Ethereum Quorum: A permissioned version of Ethereum focused on providing privacy for business enterprises.
- Hyperledger Fabric: A permissioned blockchain platform that supports smart contracts (called chaincode) developed in Go or Java.
- Corda: A distributed ledger technology (not strictly a blockchain as transactions aren't grouped in blocks) popular in the maritime and insurance sectors, supporting smart contracts in Java and Kotlin, and uniquely including legal prose.

The Smart contracts provide improved efficiency and cost reduction by streamlining the process. It also has enhanced transparency and auditability through the immutability. Increase security and fraud reduction through cryptographic blockchain. Automation of complex agreement without need for manual intervention. Faster, economical transactions with cross boarder payment and helps to build trust and confidence among the stake holders.

It also has certain limitations such difficulties in the non-quantifiable conditions, where traditional contracts have many of the non-quantifiable conditions. The code vulnerabilities In the contract can be exploited. Reliability on the external data sources (oracles). Which mean if the oracle is attacked it certainly has an effect on the smart contract. If the BC platform is small then it also effects the smart contracts so the scalability depends upon the BC. Regulatory compliance is also an issue and adaption to the existing system is a challenge. A supportive framework is required for the smooth executions of the contracts. If a public BC is used the energy consumption should also be taken into account.

3.4 System Architecture

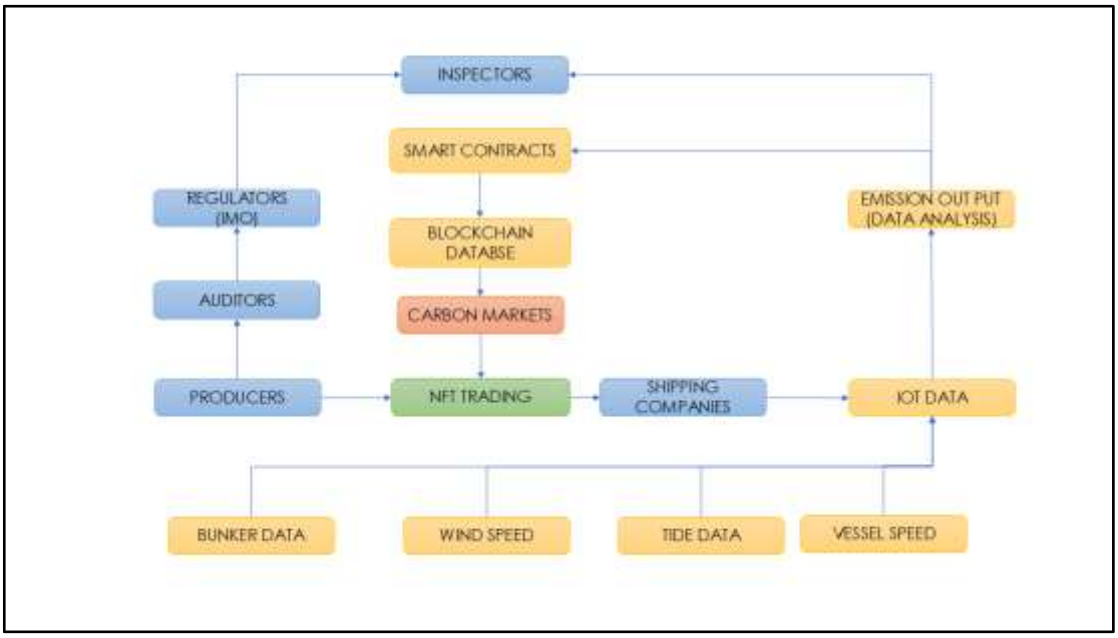


Fig: 3.2 System Architecture for carbon Credit system.

3.4.1 Data Flow

Different Users such as the Producers, Auditors, Inspectors, Shipping Companies and the Regulators(IMO) can be seen in the above diagram (Fig 3.1). The interactions are as follows. The Credit Producers (Producers), they help in the reduction of carbon emission or their process are low carbon. Example afforestation groups and Renewable energy project. These help in the reduction of Carbon. An auditor audits the project design or the processes of these Producers and allot the Credits accordingly. The allotment depends upon certain criteria.

The allotted credits can be traded in the carbon credit system or carbon markets. The other users such as the consumer is the Shipping companies where they have the compliance from IMO. And they can offset their unavoidable emission through the carbon credits. The data can be collected through the use of IoT devices which collect the wind speed, Tide Data, Vessel Speed and Bunker Data. Which is then further analysed to get much more accurate data.(Jenkins et al., 2024)[42]

These Data is also subject to the Inspections for verification of the emission data such as the Port State control, appointed by the IMO (Regulator). After using the offset of the carbon credit, the smart contract with certain quantifiable conditions is used in order to avoid the double counting and increase the integrity of the system. The smart contract automatically burns the Credit or turning them into void credits which cannot be used again. The Data is stored in a Permissioned BC database which offers much more flexibility and also can modify the rules whenever necessary. This cycle continues until the goals of the organization is achieved. The automation process of this ensures the efficiency of the system and improve the accuracy. The data from ships can be collected through the AIS (Automatic Identification System). Which can already be used to get a near-Realtime data for a Carbon Credit System.

The system is primarily driven by the Monetary incentive available for both the producer, consumer and the regulator. Which in turn helps in the generation of low carbon technological innovations for a sustainable and efficient mode for transport.

3.5 Implementation

3.5.1 Fundamentals

- As for the **Carbon Credit,** One ton of Carbon Dioxide equivalent (CO2e) is represented as one credit. These are implemented or allotted based on the verification of emission reduction or removals.

[42] Jenkins, J. G., Negangard, E. M., & Sheldon, M. D. (2024). Using Blockchain, Non-Fungible Tokens, and Smart Contracts to Track and Report Greenhouse Gas Emissions. *The Accounting Review*, 1–29. https://doi.org/10.2308/TAR-2023-0222

- The **Market Structure** is for both compliance markets (regulatory) and voluntary (Optional Offsetting). Systems like EU-ETS set emissions caps while allowing trading.
- **Verification Process** done by independent certification bodies, verify the emission reduction before issuing the credits. It can also be noted that IMO can create a new independent regulatory body which can operate in multiple countries or based on the requirement.
- **Trading Infrastructure:** Over the counter transactions through brokers are one of the methods while BC is another method which offers much more reliability. The cost of the BC infrastructure development is needed to be considered into the Infrastructure.

3.5.2 Challenges and Solutions

Table: 3.1 : Challenges and Solutions

Challenge		**Solution**
Fraud and Greenwashing	Many companies use the use of offsetting to make a claim for zero emission or carbon neutral transport	**Blockchain and Smart contract**
Double Counting	When the same emission data, credit is used again without knowledge reducing the accuracy of the data	**Automatic Retirement of Credit**
Low Trust	For the reliability and the wide spread usage of the system is required in order to be a successful system.	**Transparency + Regulatory Support**
Tech Scalability	The infrastructure primarily depends on the over-the-counter trading which cannot be scaled due to the dependency on man power	**Permissioned blockchain**
Privacy Issues	The data about the users' needs to protected and security is another concern for the users.	**Zero-Knowledge Proofs, Encrypted storage**

3.5.3 Deployment Strategy

- **Phase 1: Framework Development and Governance:** This step is the establishment of a clear policy and governance framework. This follows the Objective definition, clear goals such as reduction of GHG emissions, enabling carbon offsetting and transparent carbon market creation. Identifying the participants who can join, project developers, carbon buyers, regulators and service providers. Standards and rules creation. Legal and regulatory compliance and governance structure, which oversee the operations handle complaints, enforce penalties and update the platform based on the feedback.
- **Phase 2: Technological Infrastructure Deployment:** In this phase the BC selection comes, whether to choose for a privacy focussed(private) or a transparency focussed(public). There should be smart contract development. Followed by the IoT and Remote sensing integration, the data is directly fed into the BC database. The security measures are in place and then plan for interoperability. Since there are many other registries for MRV and trading platforms.
- **Phase 3: Stakeholder Engagement and Capacity Building:** This step identifies the Stakeholders such as the Governments, Carbon Project Developers, auditors, verifiers, buyers, NGOs, and port authorities (since it is for the maritime applications). There should be workshops and consultations to explain the benefits for the platform and operational workflows and responsibilities. The training and tech support is also part in this stage, and necessary adjustment are done through the feedback loops to make the platform much better for the users.
- **Phase 4: Pilot Testing:** System design validation where the credit issuance, trading and retirement workflows are tested under the real conditions. Identifying issues and then benchmarking. After this the platform is addressed to the regulations set by the government such EU has the Data privacy laws and adherence to the laws are maintained. (the immutability and the transparency of the BC contradicts this law, that is why it is important).
- **Phase 5: Monitoring, Enforcement and Continuous Improvement:** The system is monitored in Realtime where credit generation, transfers and retirements on the BC. Third parties are employed or a verification agency is

created for this purpose by the regulator to validate the credit quality. Since the use of Smart contracts make it easier the penalties can be made automatic when there is a case of fraud or non-compliance. Using such a platform where the users are identified makes it such an easier method to upgrade the system on the existing mechanisms and implement cybersecurity measures to improve the reliability of the systems.

3.6 Integration with Existing Systems

Smooth integration with the existing infrastructure is key to this platform. So, a BC based Carbon credit system should integrate with the carbon credit registries, emissions reporting platforms, and verification tools. Without this there will be data fragmentation and inefficiencies which undermine the system's value.

Since the modern digital world allows for the use of API's, it allows emissions data from devices or centralized database to be securely uploaded to the BC, ensuring an automatic process which is also tamper proof. It also can be utilized to get data from the traditional registries such as Verra, Gold Standard to be represented on the BC. If the public BC is used then it is possible to use the Tokenization where a unique identifier can be assigned and immutably record the data, which allows tracking from issuance to the retirement. These steps prevent the double counting, enable the full traceability where the current systems don't need to be terminated.

3.6.1 Interoperability

It refers to the system's ability to work across different platforms seamlessly. It is a vital component for the platform or the global carbon market. Ther are multiple carbon markets working in parallel such as the EU-ETS, voluntary market registries, and sectoral systems for maritime, aviation, or energy.

In order to make it much better at interoperability it much support data exchange data exchange between platforms; translate and standardize formats, such as credit units or emission metrics; operate across permissioned and public BC, which may use different protocols; and allow regulatory access for auditing and reporting purposes. The tokenization of carbon credits cannot be done on one platform if there is not interoperability making it fragmented and inefficient which defeats the purpose of this system. The development of APIs for the system to get data across platforms which will help enable a connected, verifiable and global carbon ecosystem.

3.6.2 Data Security and Privacy

As mentioned earlier the immutability make the BC ledger unalterable. This makes an ideal log for the carbon credit system. However, there might be concerns regarding the privacy and security which include the private or commercially sensitive data. To achieve the transparency and confidentiality it is better to follow these:

- **Hashing:** data is stored as digital footprint instead of full documents
- **Encryptions:** prevent access to data without authorization
- **Permissioned BC:** authorized users can only access, read or write data.
- **Zero-knowledge proofs** and other privacy-enhancing techniques can further secure sensitive records.

Compliance with data protection laws, such as **GDPR**, is essential — especially in multi-jurisdictional applications.(Tsai, 2025)[43] Together, these measures create a secure, interoperable, and privacy-aware platform that encourages trust and adoption among users and regulators.

3.7 Summary

This Chapter presents the system design and implementation of a blockchain-based carbon credit trading platform, with a special focus on maritime applications. The chapter begins by outlining the fundamentals of blockchain technology — emphasizing its decentralized, immutable, and transparent nature. It categorizes blockchains into permissioned and permissionless types, explaining their relevance to regulated industries like carbon markets and shipping.

The chapter then details the structure of a carbon credit system, where greenhouse gas emissions are reduced through market-based incentives. The blockchain platform ensures transparency and trust through smart contracts and cryptographic verification. Fraud is addressed using digital records, third-party audits, and automated credit retirement to prevent double counting. Green shipping practices are promoted through regulatory frameworks such as IMO's EEXI and CII, alongside market-based measures like carbon taxes and emission trading systems. Technological

[43] Tsai, Y. C. (2025). Enhancing Transparency and Fraud Detection in Carbon Credit Markets Through Blockchain-Based Visualization Techniques. *Electronics (Switzerland)*, *14*(1). https://doi.org/10.3390/electronics14010157

upgrades, operational improvements, and port-driven strategies are highlighted as enablers of decarbonization.

The chapter identifies different users of the system — from prosumers and regulators to ship operators and auditors — and describes their interactions in a decentralized ecosystem powered by blockchain, smart contracts, and IoT. The preferred blockchain architecture is permissioned (e.g., Hyperledger Fabric) due to its privacy, regulatory compliance, and scalability. Smart contracts automate credit issuance, trading, and verification, ensuring cost efficiency and reliability.

The deployment strategy involves five phases: governance framework development, technological infrastructure setup, stakeholder engagement, pilot testing, and continuous monitoring. Integration with existing systems is ensured through APIs and registry bridges, while interoperability across platforms is necessary for global adoption. Finally, the chapter highlights the importance of data privacy, emphasizing encryption, permissioned access, and compliance with laws like GDPR. Overall, the system is designed to ensure environmental integrity, operational transparency, and scalable global deployment.

CHAPTER IV
BLOCKCHAIN SOLUTION FOR MARITIME CARBON EMISSION: A PRACTICAL APPROACH

4.1 Importance of Blockchain: Environmental Compliance & Carbon Credit Trading

Reduction of the GHG emission and sticking to the environmental regulations such as MARPOL Annex VI, the IMO's GHG Strategy and the EU ETS (the regional frameworks). A robust, transparent and verifiable data system was required to achieve the compliance and the operational challenges would be addressed by the BC technology.

The decentralized and tamper-proof nature of ledger can record the emission data in real time from ships, ports and logistics chain. Transparency and accountability are provided through the immutable data recording feature of the BC. It can also potentially use the IoT to record the data directly and automatically in the database, it can be accessed by the stakeholders such as shipowners, regulatory bodies and classification societies. This automatic process eliminates the manual errors or the deliberate misreporting and enhance the trust among the stakeholders.

The smart contract is one of the main applications that has come out in the last decade that has enable to the idea of the automation of the process. The usage of smart contract where it can be embedded into the blockchain and thus automatically execute upon meeting the conditions. It can even use as a trigger when the ships emissions exceed a certain limit. It also provides an excellent alternative for the paper heavy and time-consuming regulatory process.

Moreover, it has a much larger role to play as the traditional systems are much more vulnerable to the fraud, double-counting and lack of verification. These vulnerabilities are addressed by BC. It also uses a feature called tokenization where it essentially makes a token for a certain amount of emission such as 1 credit for 1 tonne of CO2 emission. These tokens are also retired and cannot be used again which increases the credibility of the carbon markets and thus improving the trust and encourages a broader participation from the stakeholders. It also reduces the number of intermediaries and thus reducing the cost. In short it creates a secure, transparent and automated framework for the emission reporting and carbon trading.

4.2. Challenges and Mitigation Strategies

4.2.1 Key Challenges

Even though implementation of BC in the maritime carbon emission monitoring and carbon credit system has a lot of potential it has a lot of critical challenges that hinder the large-scale adoption.

- **Technical Barries:** These are the most pressing as many vessels and ports are still relying on the outdated systems with limited digital infrastructure. The requirement of standardized protocols across the supply chain is fragmented which hinders the integration of BC with real-time data acquisition, secure connectivity. Additionally, there is a concern for the cybersecurity and the data manipulation in digital platforms.
- **Operational Constraints:** Playing a significant role in the challenges. Ship owners, port authorities, and logistics providers often lack sufficient knowledge or exposure to the BC technology. This lack of knowledge lead to uncertainty, which increase the resistance to replacing familiar systems. Moreover, cost of implementation or the initial cost for a BC system including the training, system upgrades and maintenance are viewed as a burden for the small and medium enterprises.
- **Regulatory Gaps:** This is one of the main headaches that is felt by all the enterprise owners when there is a lack of globally accepted legal or policy framework. Similarly, there is requirement for the verification procedures for BC based carbon emission reporting and carbon trading. So technically, there should be standardization or policy backing from the global maritime institutions, which is one of the reason the players are hesitant to commit the resources toward the unregulated systems.

4.2.2 Research Methodology

This study follows a mixed-methods research methodology, combining theoretical analysis with empirical data to explore how blockchain technology can be effectively applied to monitor maritime carbon emissions and facilitate transparent carbon credit trading.

- **Review of Literature**

The review of literature formed the foundation of this research, offering critical insights into existing academic studies, industry reports, and technological developments related to blockchain and green shipping. Scholarly sources were analysed to understand the evolution of blockchain technology, particularly its application in emission monitoring, decentralized data management, and automated compliance enforcement through smart contracts. The literature also examined emission trading schemes (ETS), both voluntary and mandatory, to identify common challenges such as fraud, double-counting, lack of verification, and high administrative costs.

Moreover, special attention was given to the role of non-fungible tokens (NFTs), tokenization, and the integration of IoT devices for real-time data tracking. Research findings emphasized how blockchain can serve as a decentralized, immutable ledger capable of enhancing transparency, reducing manipulation, and simplifying regulatory reporting processes. The literature review not only informed the theoretical framework for the study but also guided the development of the system model and the formulation of research instruments.

- **System Design**

A conceptual blockchain-based system was designed to illustrate how carbon credits can be generated, tracked, verified, and traded in the maritime sector. The model is built on a **permissioned blockchain architecture**, which ensures data privacy, security, and compliance with international regulations. This design was selected for its ability to limit access to verified participants, making it ideal for regulated industries like shipping and environmental governance.

The system integrates smart contracts that automatically execute actions such as issuing, retiring, or transferring carbon credits once specific emission reduction conditions are met. Real-time data collection is facilitated through IoT-enabled devices on ships and at ports, gathering information such as bunker fuel consumption, vessel speed, and engine performance. These inputs are processed to calculate emissions and feed directly into the blockchain ledger. The system also defines the roles of various stakeholders—such as regulators, ship operators, carbon credit producers, and auditors—to ensure seamless coordination and accountability. This design serves as a prototype to demonstrate how blockchain can address key issues in carbon credit markets, such as trust deficits, delays in reporting, and regulatory inefficiencies.

- **Data Analysis**

To validate the system design and understand stakeholder perspectives, a structured questionnaire survey was conducted across professionals in shipping, logistics, port operations, and environmental compliance sectors. The survey included Likert scale items, multiple-choice questions, and ranking tasks designed to assess awareness of blockchain, perception of its benefits and challenges, and anticipated industry readiness for adoption.

The responses were analysed using **descriptive statistics** to identify trends, and **ranking analysis** to prioritize perceived challenges and advantages. Additionally, **regression analysis** was employed to test hypotheses related to awareness, transparency belief, trust in blockchain-based credit systems, and their influence on the perceived role of blockchain in decarbonization efforts. The analytical results helped identify which factors significantly impact stakeholder support for blockchain adoption in maritime emission tracking.

- **Conclusion**

The research methodology effectively integrates theoretical, technical, and practical dimensions to explore the application of blockchain in maritime decarbonization. The literature review provided conceptual clarity, the system design offered a technological framework, and the data analysis revealed stakeholder insights. Together, these methodological components support a detailed and balanced assessment of blockchain's potential to transform carbon accounting in the maritime sector. The findings contribute to ongoing efforts in digitalizing environmental compliance and offer actionable recommendations for improving transparency, trust, and efficiency in carbon credit systems.

4.2.3 Data Collection and Analysis

A survey is conducted with purpose of gathering the insights on stakeholder perceptions, priorities and practical considerations regarding the use of BC technology in reducing maritime carbon emissions. A total of 45 responses were collected from the relevant field, primarily shipping and secondarily logistics. The questionnaire was a mixture of Likert, MCQ and Ranking. Microsoft Excel was used for the Analysis of the Data Collected.

4.2.3.1 Ranking

The **Challenges,** faced by the adoption of BC technology for the maritime emission tracking and trading. The challenges are as follows: **Technical Complexity, Lack of Regulatory Support, Cost of Implementation, Lack of Awareness, Resistance to Change.**

Table: 4.1 Challenges Ranked

R	Challenges	1	2	3	4	5	Weighted Average
1	Cost of Implementation	15	17	7	4	2	3.86
2	Technical Complexity	16	11	12	3	3	3.75
3	Lack of Regulatory Support	7	8	14	10	6	3
4	Lack of Awareness	2	6	8	24	5	2.46
5	Resistance to Change	5	3	4	4	29	1.91

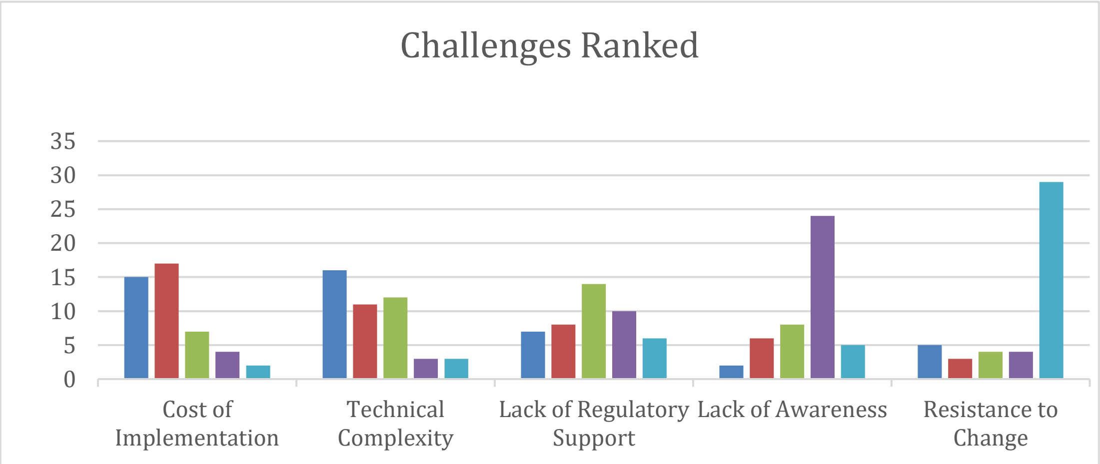


Fig. 4.1 Challenges Ranked (staked Bar Graph)

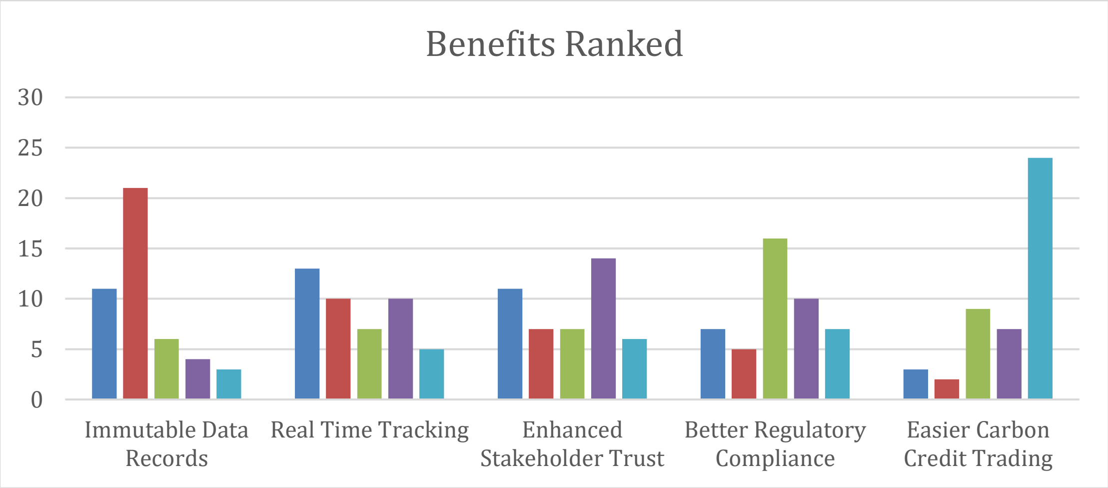
The Challenges are ranked on the basis of weighted average. The ranked are assigned a weighted score and then the average is calculated. R1to R5 is assigned 5 to 1 Respectively.

Similarly, the **Benefits,** of adoption of BC technology for the maritime emission tracking and trading. These Challenges are as follows: **Real-time Emission Tracking, Better Regulatory Compliance, Immutable Data Records, Enhanced Stakeholder Trust, Easier Carbon Credit Trading.**

Table: 4.2 Benefits Ranked

R	Benefits	1	2	3	4	5	Weighted Average
1	Immutable Data Records	11	21	6	4	3	3.73
2	Real Time Tracking	13	10	7	10	5	3.35
3	Enhanced Stakeholder Trust	11	7	7	14	6	3.06
4	Better Regulatory Compliance	7	5	16	10	7	2.89
5	Easier Carbon Credit Trading	3	2	9	7	24	1.95

Fig 4.2 Benefits Ranked (Staked Bar Graph)



The ranking data indicates that while challenges like cost and technical complexity are clearly dominant concerns, the top four benefits—particularly immutable data and real-time tracking—are consistently recognized. This suggests that stakeholders see significant value in blockchain's advantages, which could potentially offset the key barriers to its adoption in maritime emissions tracking.

4.2.3.2 Hypothesis Testing (Likert Scale and Regression)

The survey gathered insights through a Likert Scale which is categorized into the following: **Awareness, Application Awareness, Transparency Belief, Application Forecast. Trust in Credit, Industry Readiness, Efficiency Belief, Decarbonization Role.** The Likert Scale has the Value of 1(Strongly Disagree) to 5(Strongly Agree).

Awareness

Statement: *I am aware of What Blockchain Technology is*.

Table 4.3: Awareness

Scale	Frequency	Percentage
2	4	9
3	9	20%
4	18	40%
5	14	31

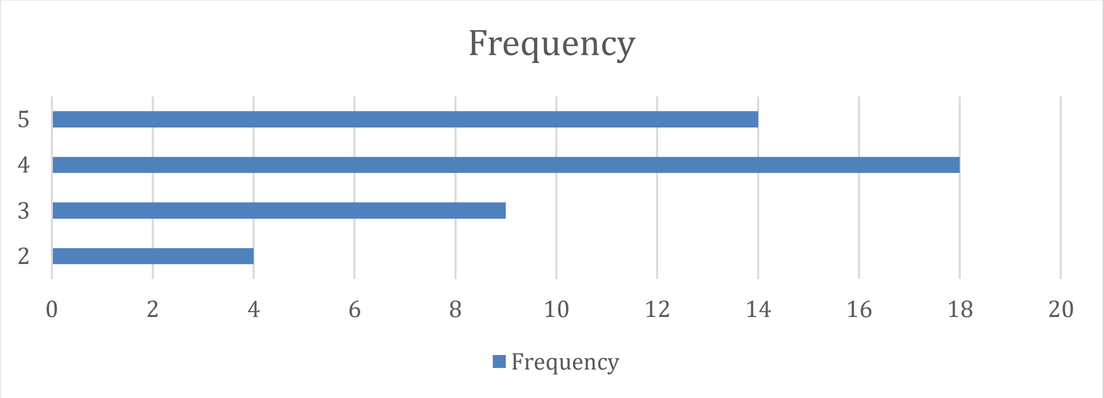


Fig 4.3: Awareness Frequency

From The Table (table no), it can be seen that there is a positive trend with 71% participants choosing 4(Agree) and 5(Strongly Agree). And very few choosing 2 (Disagree)

Application Awareness

Statement: *I understand the potential use of blockchain in monitoring maritime carbon emissions.*

Table 4.4: Application Awareness

Scale	Frequency	Percentage
2	4	9%
3	11	24
4	21	47
5	9	20

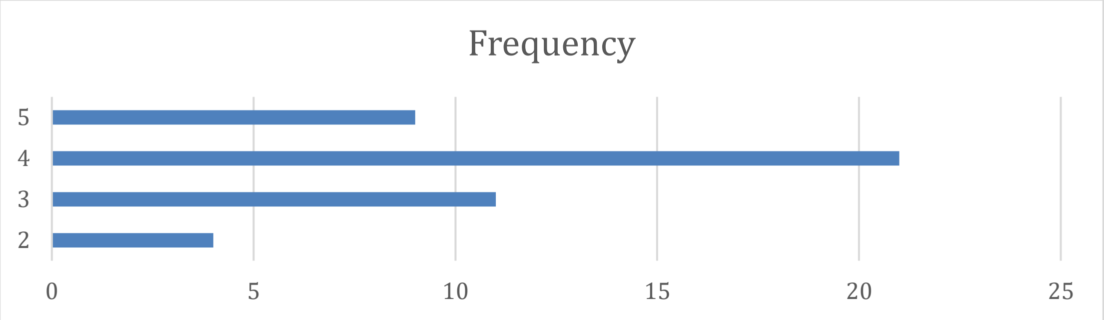


Fig 4.4: Application Awareness Frequency

From the Table it can be seen that there is a positive trend with 64% participants choosing 4(Agree) and 5(Strongly Agree) and very few choosing 2(disagree).

Transparency Belief

Statement: *Blockchain Technology can improve transparency and accountability in emission reporting.*

Table 4.5: Transparency Belief

Scale	Frequency	Percentage
2	2	4%
3	7	16%
4	17	38%
5	19	42%

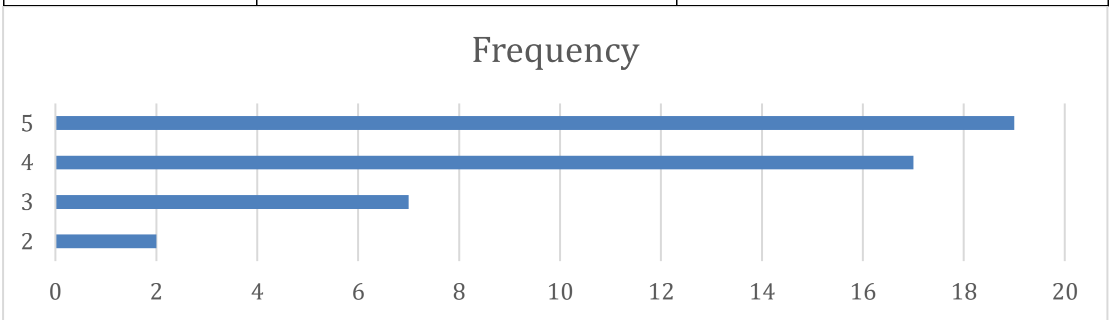


Fig 4.5: Transparency Belief Frequency

From the table it can be seen that there is a high positive trend with 80% participants choosing 4(Agree) and 5(Strongly Agree).while only 4% of participants choosing 2(disagree).

Application Forecast

Statement: *Blockchain adoption in the maritime sector is likely to grow significantly in the next five years.*

Table 4.6: Application Forecast

Scale	Frequency	Percentage
3	8	18%
4	15	33%
5	22	49%

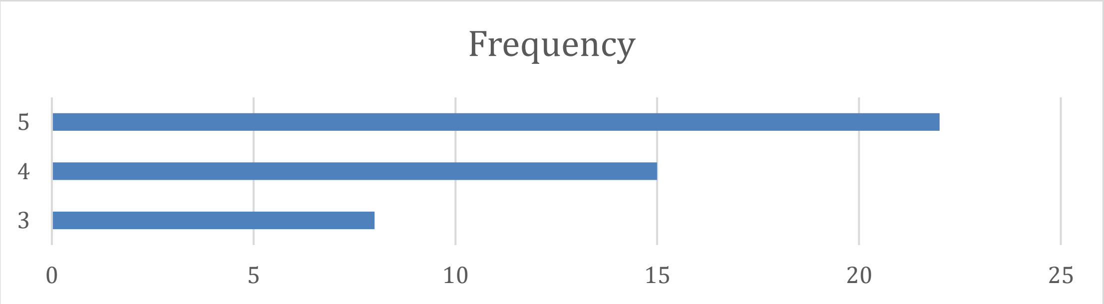


Fig 4.6: Application Forecast Frequency

From the table it can been seen that there is a very high positive trends of 82% participants choosing 4(Agree) and 5(Strongly Agree). While, no Participants choosing 2(Disagree) or 1(Strongly Disagree).

Trust in Credit

Statement: *Using blockchain for carbon credits can enhance trust among stakeholders.*

Table 4.7: Trust in Credit

Scale	Frequency	Percentage
2	3	7%
3	11	24%
4	16	36%
5	15	33

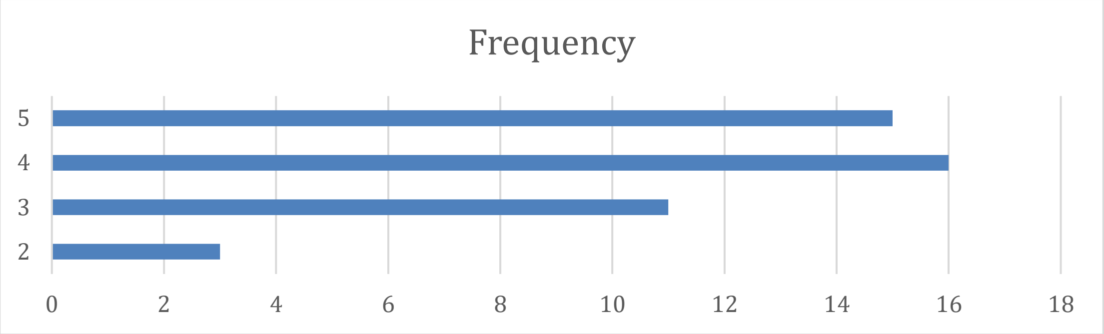


Fig 4.7: Trust in Credit Frequency

From the table it can be seen that there is a positive response of 69% participants choosing 4 and 5. While a very low 7% of negative response of 2(Disagree).

Industry Readiness

Statement: *The maritime industry is ready for digital solutions like blockchain to manage its environmental goals.*

Table 4.8: Industry Readiness

Scale	**Frequency**	**Percentage**
2	3	7%
3	14	31%
4	18	40%
5	10	22%

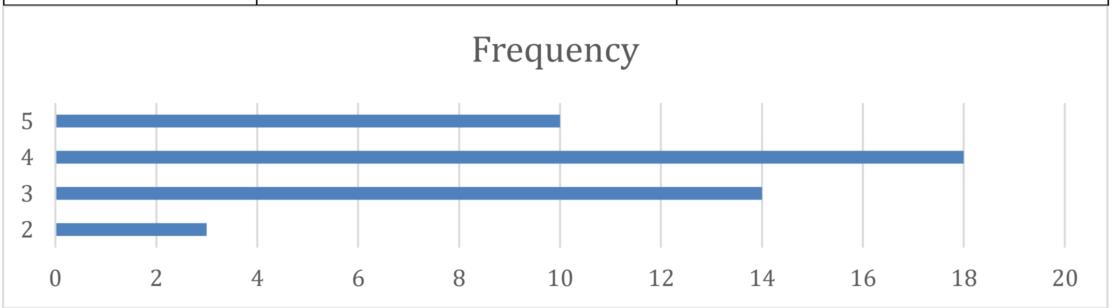


Fig 4.8: Industry Readiness Frequency

From the Table it can be seen that there is a positive response of 62% participants choosing 4 and 5. While a very few participants choosing 2.

Efficiency Belief

Statement: *Carbon credit systems integrated with blockchain will be more efficient than current systems.*

Table 4.9: Efficiency Belief

Scale	Frequency	Percentage
2	2	4%
3	11	24%
4	20	44%
5	12	27%

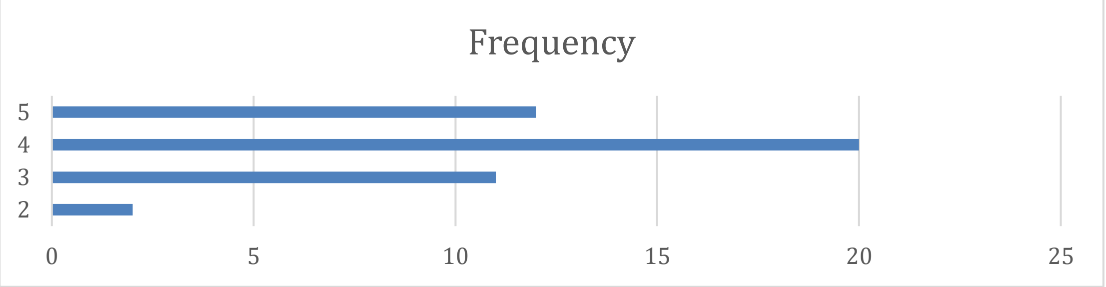


Fig 4.9: Efficiency Belief Frequency

From the table it can been seen that highly positive response of 71% participants choosing 4 and 5. While a very few participants choosing 3.

Decarbonization Role

Statement: *Do you believe blockchain can directly contribute to decarbonization efforts in maritime logistics?*

Table 4.10: Decarbonization Role

Scale	Frequency	Percentage
2	2	4%
3	21	47%
4	14	31%
5	8	18%

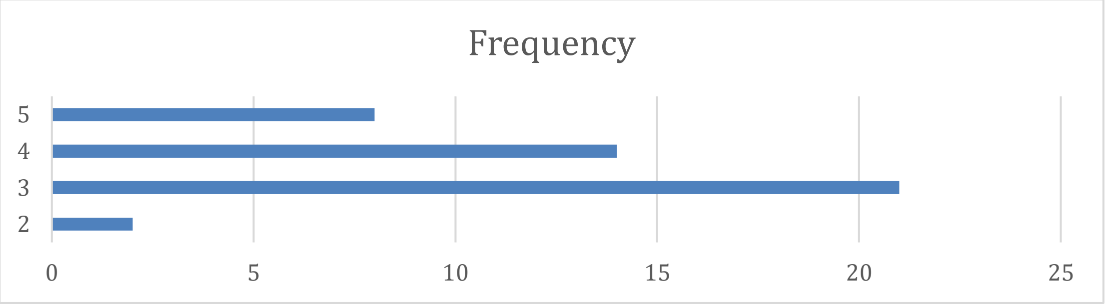


Fig 4.10: Decarbonization Role Frequency

From the table it can been seen that there is mostly a neutral response of 47% participants choosing 3 and a slight positive response of 39% participants choosing 4 and 5.

Hypothesis on Awareness

H_0a:There is no significant relation between the awareness of Blockchain technology and the Decarbonization role.

Regression Statistics	
Multiple R	0.605807
R Square	0.367002
Adjusted R Square	0.352281
Standard Error	0.670919
Observations	45

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	11.22211	11.22211	24.93071	1.04E-05
Residual	43	19.35567	0.450132		
Total	44	30.57778			

Table 4.11: Summary of Hypothesis on Awareness

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.506872852	0.435302767	3.461666147	0.001225925	0.629001158	2.384744547	0.629001158	2.384744547
Awareness	0.537800687	0.107709501	4.993066357	1.0355E-05	0.320583776	0.755017598	0.320583776	0.755017598

The regression analysis was conducted to examine the relationship between Awareness and the dependent variable. The results indicate that Awareness has a statistically significant positive impact on the dependent variable, as shown by a **coefficient of 0.5378** and a **p-value of 0.000010355**, which is well below the 0.05 significance level. This means we reject the null hypothesis and conclude that increased Awareness is associated with an increase in the dependent variable. The model explains approximately **36.7% (R^2 = 0.367)** of the variation in the outcome, suggesting a moderate fit. Thus, Awareness plays a meaningful and significant role in influencing the outcome being measured.

Hypothesis on Application Awareness

H_0b: There is no significant relation between the awareness of Blockchain Application Awareness and the Decarbonization role

Regression Statistics	
Multiple R	0.411421
R Square	0.169267
Adjusted R Square	0.149947
Standard Error	0.768598
Observations	45

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5.175804	5.175804	8.761507	0.004989
Residual	43	25.40197	0.590744		
Total	44	30.57778			

Table 4.12: Summary of Hypothesis on Application Awareness

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.143421	0.512567	4.181734	0.00014	1.10973	3.177112	1.10973	3.177112
Application Awareness	0.391447	0.132246	2.959984	0.004989	0.124747	0.658148	0.124747	0.658148

The regression analysis was conducted to examine the relationship between Application Awareness and the dependent variable. The results indicate that Application Awareness has a statistically significant positive impact on the dependent variable, as shown by a **coefficient of 0.3914** and a **p-value of 0.004989**, which is well below the 0.05 significance level. This means we reject the null hypothesis and conclude that higher levels of Application are associated with an increase in the dependent variable. The model explains approximately **16.9% (R^2 = 0.1693)** of the variation in the outcome, indicating a weak to moderate fit. Nonetheless, Application Awareness contributes meaningfully and significantly to predicting the outcome.

Hypothesis on Transparency Belief

H_0c: There is no significant relation between the Transparency Belief and the Decarbonization role.

Regression Statistics	
Multiple R	0.507644
R Square	0.257702
Adjusted R Square	0.240439
Standard Error	0.726537
Observations	45

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7.879961	7.879961	14.92823	0.000372
Residual	43	22.69782	0.527856		
Total	44	30.57778			

Table 4.13: Summary of Hypothesis on Transparency Belief

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.567531	0.54271	2.888342	0.006041	0.473053	2.662009	0.473053	2.662009
Transparency Belief	0.491814	0.127291	3.863707	0.000372	0.235108	0.748521	0.235108	0.748521

Table 4.13: Summary of Hypothesis on Transparency Belief

The regression analysis was conducted to assess the effect of Transparency Belief on the dependent variable. The results show that Transparency Belief has a statistically significant positive effect, with a **coefficient of 0.4918** and a **p-value of 0.000372**, which is well below the 0.05 significance threshold. Therefore, we reject the null hypothesis and conclude that increases in Transparency are associated with increases in the dependent variable. The model explains **25.77% (R^2 = 0.2577)** of the variation in the dependent variable, reflecting a modest but meaningful fit.

Hypothesis on Application Forecast

H_0d: There is no significant relation between the Application Forecast and the Decarbonization role

Regression Statistics	
Multiple R	0.403136
R Square	0.162519
Adjusted R Square	0.143042
Standard Error	0.771714
Observations	45

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.969459	4.969459	8.344426	0.006036
Residual	43	25.60832	0.595542		
Total	44	30.57778			

Table 4.14: Summary of Hypothesis on Application Forecast

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.724437	0.666971	2.585474	0.013198	0.379361	3.069512	0.379361	3.069512
Application Forecast	0.440208	0.152391	2.888672	0.006036	0.132882	0.747534	0.132882	0.747534

The regression analysis was conducted to assess the effect of **Application Forecast** on the dependent variable. The results show that Application Forecast has a statistically significant positive effect, with a **coefficient of 0.4402** and a **p-value of 0.006037**, which is below the 0.05 significance threshold. Therefore, we reject the null hypothesis and conclude that improvements in Application Forecast are significantly associated with increases in the dependent variable. The model explains **16.25% (R^2 = 0.1625)** of the variation in the dependent variable, suggesting a weak to modest fit.

Hypothesis on Trust in Credit

H_0e: There is no significant relation between the Trust in Credit and the Decarbonization role

Regression Statistics	
Multiple R	0.741446127
R Square	0.549742359
Adjusted R Square	0.539271251
Standard Error	0.565847339
Observations	45

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	16.8098997	16.8098997	52.50087799	5.68102E-09
Residual	43	13.76787808	0.320183211		
Total	44	30.57777778			

Table 4.15: Summary of Hypothesis on Trust in Credit

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.988276671	0.373174292	2.64829784	0.011266278	0.235698988	1.740854354	0.2356 98988	1.7408 54354
Trust in Credit	0.665885111	0.0919 00108	7.24574896	5.68102E-09	0.480550881	0.851219342	0.4805 50881	0.8512 19342

The regression analysis was conducted to assess the effect of Trust in Credit on the dependent variable. The results show that Trust in Credit has a statistically significant positive effect, with a **coefficient of 0.6659** and a **p-value of 5.68102E-09**, which is far below the 0.05 significance threshold. Therefore, we reject the null hypothesis and conclude that increases in Trust in Credit are significantly associated with increases in the dependent variable. The model explains **54.97% (R^2 = 0.5497)** of the variation in the dependent variable, suggesting a moderate to strong model fit.

Hypothesis on Industry Readiness

H_0f: There is no significant relation between the Industry Readiness and the Decarbonization role

Regression Statistics	
Multiple R	0.255841335
R Square	0.065454789
Adjusted R Square	0.043721179
Standard Error	0.815208859
Observations	45

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.001461988	2.001461988	3.011685136	0.089828783
Residual	43	28.57631579	0.664565483		
Total	44	30.57777778			

Table 4.16: Summary of Hypothesis on Industry Readiness

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.702631579	0.543651317	4.97125914	1.11211E-05	1.606254209	3.799008949	1.606254209	3.799008949
Industry Readiness	0.243421053	0.140266304	1.735420737	0.089828783	-0.039452908	0.526295014	-0.039452908	0.526295014

The regression analysis was conducted to assess the effect of Industry Readiness on the dependent variable. The results show that Industry Readiness does not have a statistically significant effect, with a **coefficient of 0.2434** and a **p-value of 0.0898**, which is greater than the 0.05 significance threshold. Therefore, we fail to reject the null hypothesis and conclude that changes in Industry Readiness are not significantly associated with changes in the dependent variable. The model explains only **6.55% (R^2 = 0.0655)** of the variation in the dependent variable, suggesting a poor model fit.

Hypothesis on Efficiency Belief

H_0g: There is no significant relation between the Efficiency belief and the Decarbonization role.

Regression Statistics	
Multiple R	0.614775934
R Square	0.377949449
Adjusted R Square	0.363483157
Standard Error	0.665091767
Observations	45

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	11.55685426	11.55685426	26.12621477	7.02303E-06
Residual	43	19.02092352	0.442347059		
Total	44	30.57777778			

Table 4.17: Summary of Hypothesis on Efficiency Belief

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.212842713	0.481689481	2.517893293	0.015610321	0.241423295	2.184262131	0.241423295	2.184262131
Efficiency Belief	0.612554113	0.119841218	5.111380906	7.02303E-06	0.370871263	0.854236962	0.370871263	0.854236962

The regression analysis was conducted to assess the effect of Efficiency Belief on the dependent variable. The results show that Efficiency Belief has a statistically significant effect, with a **coefficient of 0.6126** and a **p-value of 7.02×10^{-6}**, which is well below the 0.05 significance threshold. Therefore, we reject the null hypothesis and conclude that changes in Efficiency Belief are **significantly associated** with changes in the dependent variable. The model explains **37.79% (R^2 = 0.3779)** of the variation in the dependent variable, indicating a moderately strong model fit.

Regression Analysis Conclusion

Table 4.18: Regression Analysis Conclusion

Hypothesis	P Value	Coeff.	R^2(%)	Model Fit	F	Conclusion
Awareness	1.0355E-05	0.53780	36.7	Moderate Fit	24.93	Significant, 36.7% variance explained
Application Awareness	0.004980	0.3914	16.9	Weak to Moderate Fit	8.76	Significant, 16.9% variance explained
Transparency Belief	0.00037	0.4918	25.7	Weak to Moderate Fit	14.92	Significant, 25.7% variance explained
Application Forecast	0.00603	0.4402	16.2	Weak to Moderate fit	8.34	Significant, 16.2% variance explained
Trust in Credit	5.68102E-09	0.6658	54.9	Moderate to Strong Fit	52.5	Significant, 54.9% variance explained
Industry Readiness	0.08982	0.2434	6.5	Weak Fit	3.01	Not Significant,6.5% variance explained
Efficiency Belief	7.02303E-06	0.6125	37.7	Moderate Fit	26.1	Significant, 37.7% variance explained

Among the seven hypotheses tested, 'Industry Readiness' is the only factor where the null hypothesis could not be rejected ($p = 0.08982$), and the model exhibits a weak fit with an R^2 of only 6.5%. This indicates that, based on the survey data, there is insufficient evidence to claim that industry readiness significantly influences the adoption of blockchain for decarbonization. While industry stakeholders may perceive themselves as prepared, this readiness does not appear to translate into a meaningful statistical impact on decarbonization efforts within the current model.

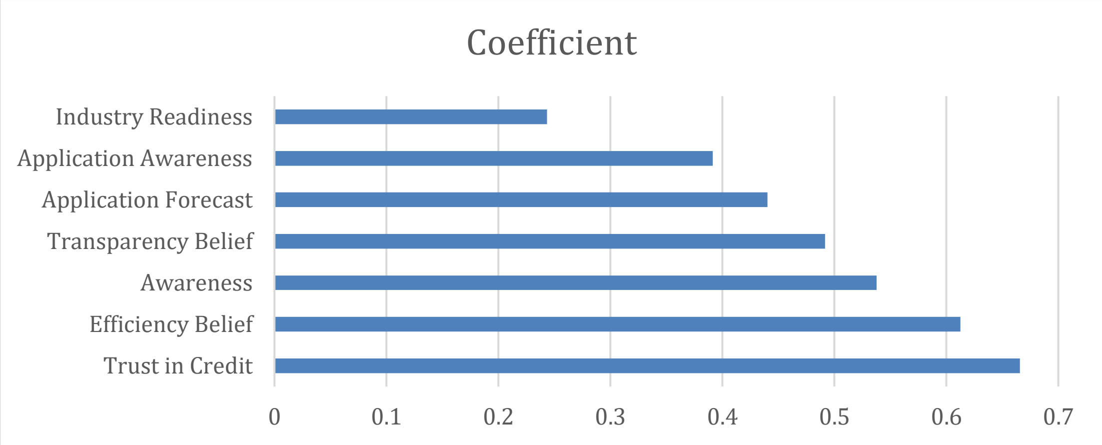


Fig 4.11: Coefficient Relation Graph with Dependent Variable(Decarbonization Role)

The graph illustrates the strength of relationship (coefficient values) between each independent variable and the dependent variable—Decarbonization Role of Blockchain (BC) technology. Among the variables, 'Industry Readiness' shows the weakest positive association, while 'Trust in Credit' demonstrates the strongest. This suggests that trust in credit systems may play a more influential role in supporting blockchain's decarbonization potential compared to the industry's perceived readiness.

4.2.3.3 Multiple Choice (Scenario Based)

The Multiple-choice question was given on the scenario in order to give the practicality of the application of BC technology for the Maritime Emissions.

A port starts using blockchain for real-time emission monitoring. What impact would this have on your trust in their sustainability efforts?

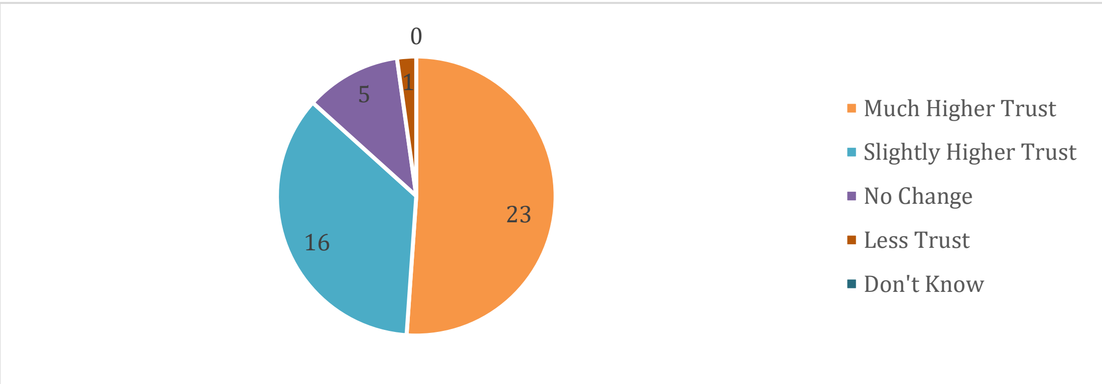


Fig4.12: Trust on Ports with Blockchain Adoption for Maritime Emissions

If given the opportunity, how likely are you to support the implementation of blockchain for emission tracking in a maritime project?

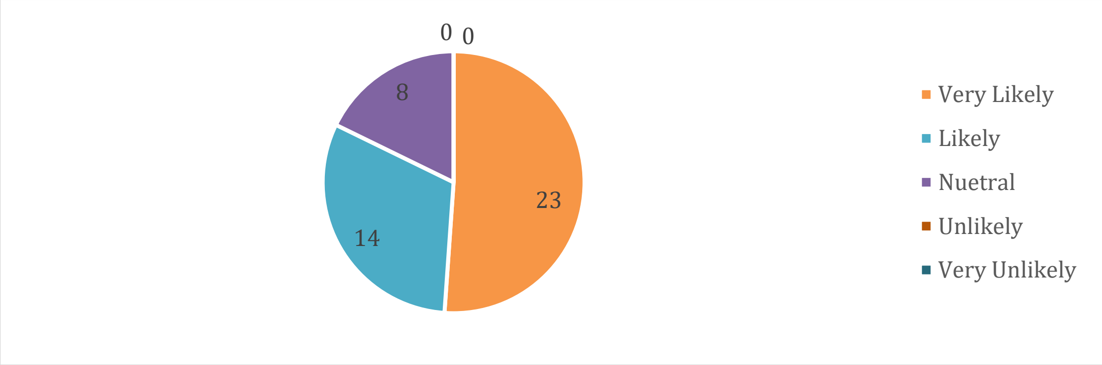


Fig4.13: Support on Implementation of Blockchain on Maritime Emission

Imagine a situation where carbon credit fraud is discovered in maritime shipping. Do you think blockchain could have prevented it?

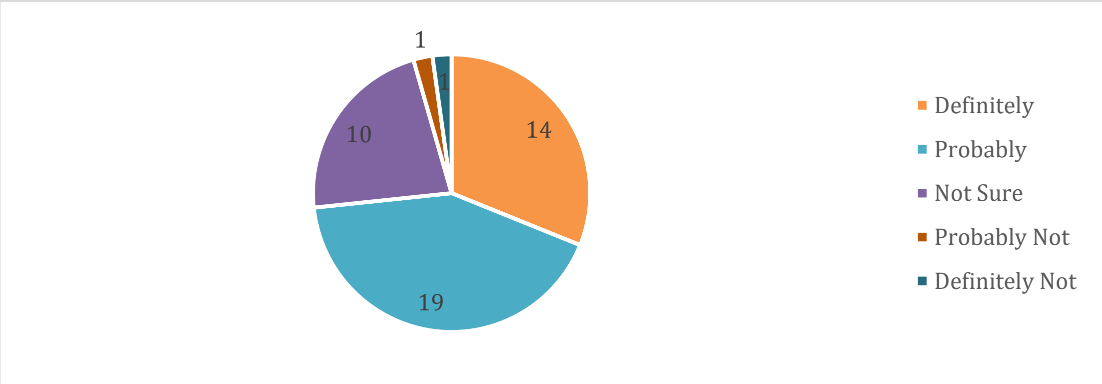


Fig 4.14: Fraud Prevention through blockchain

In your opinion, what is the biggest hurdle for blockchain adoption in maritime emissions tracking?

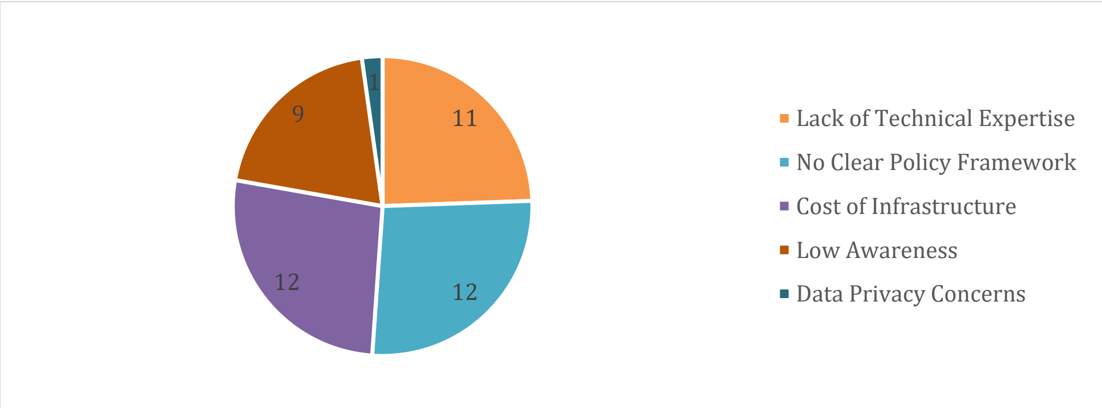


Fig 4.15: Blockchain adoption Hurdle

The responses indicate an overall positive perception toward the adoption of blockchain technology for maritime emission monitoring. A significant portion of participants expressed increased trust in ports implementing blockchain, with many indicating a willingness to support its implementation. Furthermore, there is a moderate belief that blockchain can help prevent fraud in carbon credit systems.

However, when asked about barriers to adoption, responses were distributed fairly evenly across issues such as technical expertise, policy frameworks, and cost. This implies that blockchain adoption in this context will require a holistic approach addressing multiple challenges simultaneously rather than focusing on a single area of concern.

4.2.4 Mitigation Strategies

To overcome the identified challenges and promote the effective implementation of blockchain in maritime carbon emission management, a multi-pronged mitigation approach is necessary.

- **Addressing Technical Barriers:** Investing in digital infrastructure upgrades across ports and vessels is essential. Cloud-based blockchain solutions with user-friendly interfaces can help lower the barrier to entry. To combat the lack of expertise, organizations can partner with tech firms or conduct targeted training programs to build internal capacity. Emphasis should also be placed on cybersecurity frameworks to protect sensitive environmental and operational data.
- **Tackling Operational Resistance:** Raising awareness through industry workshops, case studies, and pilot project demonstrations can help shift perceptions. Financial incentives such as subsidies or tax benefits may be introduced to offset initial implementation costs, especially for small operators. Involving end-users in early project phases will improve acceptance and reduce resistance to change.
- **Bridging Regulatory Gaps:** Global maritime bodies, particularly the IMO, need to collaborate with national governments to draft standardized regulatory frameworks for blockchain-enabled emission tracking and carbon credit validation. Policymaking should prioritize interoperability and legal clarity, ensuring that carbon credits issued through blockchain are recognized under compliance and market-based mechanisms.

4.3 Advancement and Technological Innovations

The maritime industry is increasingly adopting blockchain technology to enhance transparency, efficiency, and accountability in carbon emissions tracking and carbon credit systems. These advancements aim to support the sector's transition towards sustainability and compliance with international environmental regulations.

- **Blockchain-Assisted Environmental Compliance Monitoring:** A secure framework integrating blockchain with IoT and shipboard sensors has been proposed to ensure real-time maritime environmental compliance. This system utilizes smart contracts to automate compliance verification and notify authorities in case of non-compliance, enhancing MARPOL enforcement through transparent and immutable record-keeping of environmental data.
- **AI-Driven Emission Tracking:** FuelTrust's Carbon Baseline solution combines AI and blockchain to calculate greenhouse gas emissions over a vessel's lifetime. By storing data on a permissioned blockchain, it ensures tamper-proof records, facilitating accurate carbon credit applications and compliance with the International Maritime Organization's emission reduction targets (Nair, 2022)[44].
- **Smart Contracts for Carbon Credit Issuance:** In port operations, smart contracts are being utilized to automate carbon credit issuance. These contracts execute transactions automatically when predefined emission reduction goals are met, reducing administrative burdens and ensuring real-time responsiveness. Such systems promote efficiency and transparency in carbon credit trading.
- **Digital MRV Solutions:** The integration of blockchain with Monitoring, Reporting, and Verification (MRV) systems enhances the credibility of carbon offsetting. Platforms like Coorest use satellite data and blockchain to track and verify carbon sequestration projects, ensuring that carbon credits represent actual environmental benefits (Coorest, 2024)[45].
- **Incentive Systems for Emission Reduction:** Blockchain-powered incentive systems have been proposed to promote Just-In-Time (JIT) arrival operations and decarbonization in maritime shipping. By issuing recognition tokens based on performance metrics, these systems encourage stakeholders to adopt efficient practices, contributing to overall emission reductions.

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[44] Nair, S. (2022, February 16). FuelTrust launches AI-based solution for assessing GHG emissions. *Ship Technology*. https://www.ship-technology.com/news/fueltrust-ai-based-solution/

[45] Coorest. (2024, November 24). Coorest is more than just a technology company! - Coorest - Medium. *Medium*. https://coorest-official.medium.com/coorest-is-more-than-just-a-technology-company-194d70e73053

- **Fuel Traceability and Quality Assurance:** BunkerTrace has developed a solution combining synthetic DNA tagging and blockchain to track marine fuel quality and origin. This technology ensures compliance with environmental regulations and prevents the use of substandard fuels, promoting sustainability in maritime operations (Ledger Insights, 2022)[46].

4.4 Summary of the Chapter

This chapter explores the potential of blockchain (BC) technology in addressing the maritime industry's carbon emission challenges, focusing on its role in compliance, monitoring, and carbon credit trading. Blockchain’s key advantages—decentralization, transparency, immutability, and automation through smart contracts—make it suitable for creating a secure and verifiable emission reporting system. Features such as real-time data logging via IoT and tokenization of carbon credits enhance stakeholder trust and eliminate fraud, double-counting, and manual errors in emission tracking.

Despite its promise, several barriers hinder BC’s adoption. Technical challenges include outdated infrastructure, lack of interoperability, and cybersecurity concerns. Operationally, limited awareness, high implementation costs, and resistance to change—especially among small and medium enterprises—pose significant hurdles. Regulatory uncertainty and the absence of a globally accepted legal framework further compound these issues.

A stakeholder survey conducted with 45 participants revealed that "Cost of Implementation" and "Technical Complexity" are the top challenges. However, the highest-ranked benefits were "Immutable Data Records" and "Real-time Emission Tracking." Likert scale responses showed generally positive attitudes toward BC's application in transparency, regulatory compliance, and carbon credit trust. Regression analysis confirmed that factors like awareness, application forecast, and trust in blockchain-based credits significantly influence stakeholder belief in its role in decarbonization—except for "Industry Readiness," which showed no significant correlation.

[46] Ledger Insights. (2022, August 5). *Green maritime consortium to use blockchain in biofuels pilot*. Ledger Insights - Blockchain for Enterprise. https://www.ledgerinsights.com/maritime-consortium-blockchain-biofuel-pilot-bunkertrace/

Mitigation strategies proposed include investing in digital infrastructure, offering financial incentives, and developing standardized regulatory frameworks through global institutions like the IMO. Lastly, technological advancements, such as blockchain-enabled MRV systems and smart contracts for compliance, indicate growing interest and experimentation in the maritime sector. While adoption is still in its early stages, the trajectory is positive, suggesting blockchain could become a central tool in the industry's transition to more sustainable and accountable operations.

CHAPTER V
CONCLUSION AND SUGGESTIONS

5.1 Findings

This study has explored the transformative potential of blockchain technology in addressing the environmental challenges faced by the maritime industry, with a particular focus on carbon emissions monitoring and carbon credit trading. The maritime sector, which facilitates nearly 80% of global trade by volume, is responsible for about 3% of global CO_2 emissions—a figure that could rise by 50–250% by 2050 without substantial intervention. In this context, blockchain emerges as a promising technological solution that can support the sector's transition toward greater sustainability, regulatory compliance, and operational transparency.

By leveraging blockchain's decentralized, immutable, and transparent nature, the maritime industry can enhance the accuracy and integrity of emissions data. When integrated with IoT sensors and onboard monitoring equipment, blockchain enables real-time, tamper-proof tracking of key pollutants—including CO_2, nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter. This approach reduces manual errors and curtails the risk of data manipulation, supporting compliance with international environmental mandates such as IMO's MARPOL Annex VI and the 2020 global sulphur cap.

Smart contracts further strengthen this system by automating compliance verification and enforcement. These self-executing codes can instantly match emissions data against regulatory thresholds (e.g., under the IMO GHG Strategy and EU ETS), issuing alerts or penalties when deviations occur. This not only minimizes administrative burdens but also enhances enforcement consistency across jurisdictions, ensuring adherence to standards such as the Energy Efficiency Design Index (EEDI) and Carbon Intensity Indicator (CII). Given that the maritime sector incurs over $60 billion annually in regulatory compliance costs, blockchain-driven automation offers a compelling case for cost reduction and improved data governance.

The integration of blockchain into carbon markets also provides a transparent and traceable framework for issuing, trading, and retiring carbon credits. Current carbon credit systems face challenges such as fraud, double counting, and over-allocation, particularly in mechanisms like the EU-ETS. Blockchain, through platforms like VeChainThor or Hyperledger Fabric, enables tokenization of credits and secures peer-to-peer trading via smart contracts. This transparency incentivizes sustainable investments—ranging from LNG- and hydrogen-powered vessels to operational practices like slow steaming, which can reduce emissions by up to 27% through a 10% speed cut.

Table 5.1: Relation to the Objectives (from data analysis, chapter 4)

Aspect	**Key Finding**	**Related Objective**
Challenges	High cost, technical barriers, lack of regulations	All objectives (implementation feasibility)
Benefits	Immutable records, real-time tracking, credit market efficiency	Platform development, real-time credit exchange
Transparency Belief	80% belief blockchain enhances transparency	Strengthen regulatory compliance
Decarbonization Uncertainty	39% see direct; 47% are neutral	Clarify blockchain's indirect role in decarbonization
Trust in Credits	Trust strongly influences decarbonization belief (R^2=54.9)	Encourage green practices, credit system credibility
Market Validation	KlimaDAO and others show blockchain carbon markets are rapidly expanding	Proves feasibility of similar maritime applications

The maritime industry is already experimenting with a wave of blockchain-enabled innovations. Examples include AI-enhanced MRV systems like FuelTrust's Carbon Baseline, fuel traceability platforms such as BunkerTrace, and blockchain-integrated AIS-based emission tracking. These technologies improve monitoring precision, reduce verification costs, and streamline compliance with frameworks such as SEEMP and EEDI. Such developments underscore the readiness of the maritime ecosystem to embrace blockchain as part of a broader digital transformation aligned with global decarbonization goals, including the Paris Agreement.

KlimaDAO is a blockchain tokenized Carbon Market. Which has retired over $4B worth of carbon credits. Which indicates the growth of the carbon credit system.

The global voluntary carbon market is valued at $479B which also has CAGR of 39.4% in 2023 (Jayaraman, 2024)[47](KlimaDAO)[48].

5.2 Conclusion

This study has explored the transformative potential of blockchain technology in addressing the environmental challenges faced by the maritime industry, particularly in the areas of carbon emission monitoring and carbon credit trading. Through a comprehensive analysis of stakeholder perceptions, literature reviews, and system design proposals, the research has demonstrated that blockchain offers a robust framework for enhancing transparency, efficiency, and trust in maritime carbon management. The findings align with the project's objectives: developing a blockchain platform to track maritime carbon emissions, enhancing regulatory compliance, promoting environmentally friendly shipping practices through a verifiable carbon credit system, and facilitating real-time carbon credit exchange. However, the study also underscores significant challenges that must be addressed to ensure successful implementation. This conclusion synthesizes the key insights, evaluates the achievement of the project's objectives, and reflects on the broader implications for the maritime sector and global decarbonization efforts.

The survey of 45 stakeholders from the shipping and logistics sectors provided critical insights into the perceived benefits and barriers of blockchain adoption. Stakeholders highly valued blockchain's ability to provide immutable data records (3.73 ranking) and real-time emission tracking (3.35 ranking), which directly support the objective of developing a blockchain platform for accurate and transparent emission monitoring. The strong belief in blockchain's potential to enhance transparency and accountability (80% agreement) and streamline regulatory compliance (2.89 ranking) validates the objective of strengthening regulatory mechanisms. Furthermore, the recognition of easier carbon credit trading (1.95 ranking) and trust in blockchain-based credits (69% agreement) aligns with the goals of creating a verifiable carbon credit system and facilitating real-time exchanges. These findings confirm that blockchain is perceived as a viable solution to the

[47] Jayaraman, P. (2024, December 24). *Top 10 Blockchain-Based Carbon Credit Platforms*. IdeaUsher. https://ideausher.com/blog/top-10-blockchain-based-carbon-credit-platforms/
[48] *Real world assets driving real-world impact*. (n.d.). KlimaDAO. https://www.klimadao.finance/

inefficiencies, fraud, and lack of transparency that plague traditional carbon accounting and trading systems in the maritime industry.

Despite this optimism, the survey highlighted significant barriers to adoption, including high implementation costs (3.86 ranking), technical complexity (3.75 ranking), and lack of regulatory support (3.00 ranking). These challenges underscore the need for strategic interventions, such as investing in digital infrastructure, developing user-friendly blockchain solutions, and collaborating with international bodies like the International Maritime Organization (IMO) to establish standardized regulatory frameworks. The uncertainty regarding blockchain's direct contribution to decarbonization (39% agreement, 47% neutral) further suggests that while blockchain excels in data management and compliance, its role in achieving actual emission reductions may require integration with complementary strategies, such as alternative fuels, slow steaming, or market-based measures like carbon taxes. This nuanced perspective highlights the importance of viewing blockchain as part of a broader ecosystem of decarbonization solutions rather than a standalone fix.

The literature review on green shipping with blockchain reinforced these findings by illustrating blockchain's practical applications, such as smart contracts for automated compliance, IoT integration for real-time data collection, and tokenization to prevent double counting in carbon credit trading. The review also emphasized the global context of maritime decarbonization, noting the IMO’s strategies (e.g., Energy Efficiency Design Index, Carbon Intensity Indicator) and regional frameworks like the EU Emissions Trading System (ETS). These align with the project’s system design, which proposes a permissioned blockchain (e.g., Hyperledger Fabric) to balance privacy, scalability, and regulatory compliance, and smart contracts to automate credit issuance and retirement. The integration of IoT devices and Automatic Identification Systems (AIS) for near real-time data collection further enhances the system's feasibility, addressing the stakeholder demand for real-time tracking.

The objectives were largely achieved through the proposed system design and stakeholder validation. The development of a blockchain platform was supported by the high stakeholder valuation of immutable records and real-time tracking, with the system architecture incorporating IoT, smart contracts, and permissioned blockchains to meet these needs. Regulatory compliance was addressed through automated verification and transparent ledgers, which stakeholders believed would reduce administrative burdens and enhance enforcement. The verifiable carbon credit system was validated by the strong trust in blockchain-based credits and the proposed use of tokenization to prevent fraud. Finally, the real-time carbon credit exchange was supported by the system's design for instantaneous trading and stakeholder recognition of blockchain's efficiency (71% agreement). However, the objective of directly reducing global carbon emissions through real-time exchanges requires further exploration, given the neutral stance on blockchain's decarbonization role.

The broader implications of this study extend beyond the maritime sector. By demonstrating blockchain's potential to overhaul carbon management, the research offers a blueprint for other high-emission industries, such as energy or manufacturing, where transparency and real-time data are critical. The emphasis on interoperability and data security (e.g., encryption, zero-knowledge proofs) ensures that the proposed system can integrate with global carbon markets, supporting frameworks like the Paris Agreement. Moreover, the study highlights the importance of stakeholder engagement and capacity building, as evidenced by the proposed deployment strategy, which includes workshops, pilot testing, and regulatory collaboration. These steps are essential for overcoming resistance to change and building trust in digital solutions.

5.3 Suggestions

The findings from the stakeholder survey, literature review, and proposed system design highlight the significant potential of blockchain technology in enhancing carbon emission monitoring and carbon credit trading in the maritime sector. While stakeholders acknowledged its benefits—such as immutable data records (3.73 ranking), real-time tracking (3.35), and transparency (80% agreement)—barriers including high implementation costs (3.86), technical complexity (3.75), and regulatory uncertainty (3.00) must be addressed. The following suggestions aim to overcome these challenges and support the development of a sustainable blockchain-based platform.

1. Addressing Implementation Challenges

To reduce costs, stakeholders can leverage open-source platforms like Hyperledger Fabric, which offer scalability and compliance at lower costs. Funding through public-private partnerships and phased implementation—starting with pilot projects in select ports—can minimize initial expenses. To address technical complexity, targeted training programs for maritime professionals in blockchain, IoT, and smart contracts should be introduced. Standardizing protocols between systems like AIS and port management tools will further ease integration. Regulatory challenges can be tackled by collaborating with global bodies such as the IMO and regional authorities like the EU ETS. Regulatory pilots can help demonstrate blockchain's compliance potential, paving the way for formal inclusion in emission regulations.

2. Enhancing Stakeholder Engagement and Trust

With 82% of respondents showing willingness to adopt blockchain and 69% expressing trust in blockchain-based carbon credit systems, engagement is crucial. Launching real-world pilot projects in major maritime hubs can validate blockchain's effectiveness in emission tracking and fraud prevention. These pilots can serve as feedback loops for refining the system design. Stakeholder education must continue through workshops and webinars, especially as 71% are already aware and 64% understand blockchain's relevance. Sharing case studies from successful implementations in other sectors, like IBM's Food Trust, can further boost confidence. Forming a collaborative consortium involving shipping companies, ports, regulators, tech firms, and NGOs will foster shared responsibility and reduce individual risk. (IBM,2020)

3. Clarifying Blockchain's Role in Decarbonization

Despite the system's transparency and efficiency, only 39% of stakeholders agreed that blockchain directly supports decarbonization, with 47% remaining neutral. This highlights the need to combine blockchain with green technologies—such as hydrogen fuels, slow steaming, and EEXI compliance. Blockchain can validate fuel usage, enabling effective policy enforcement. It can also complement market-based measures like carbon taxes and green incentives. Further research should be conducted to quantify blockchain's indirect contributions, such as reduced administrative burdens or improved route optimization. Establishing global standards for blockchain-based carbon markets will ensure integrity and prevent double counting.

4. Facilitating Real-Time Carbon Credit Exchange

To enable efficient carbon trading, a user-friendly digital platform should be developed, integrating AIS and IoT data for accurate emissions reporting. Smart contracts will automate transactions and enhance reliability. The platform should align with global schemes such as the EU ETS to enable international credit trading. Incentivizing participation through lower transaction fees and early-adopter benefits can improve adoption. Linking with voluntary carbon markets will enhance liquidity.

Security features like encryption and zero-knowledge proofs must be implemented to safeguard data and maintain regulatory compliance.

5. Ensuring Long-Term Sustainability

For long-term impact, a dedicated governance body should oversee the blockchain platform, monitor KPIs (e.g., emission reductions, transaction volumes), and update smart contracts. Regular audits will ensure credibility and deter misuse. The platform should be designed for interoperability, extending to other industries like aviation. Collaborations with existing carbon registries can expand its global reach. Finally, policy advocacy is essential—encouraging updates to IMO regulations and promoting international standards for blockchain-based carbon accounting.

5.4 Limitations

While this study presents a comprehensive framework for implementing blockchain in maritime carbon emission tracking and carbon credit trading, several limitations must be acknowledged.

Limited Sample Size and Representation

The stakeholder survey involved 45 participants, offering valuable insights but lacking the diversity needed to represent the full spectrum of global maritime stakeholders. Smaller operators, developing countries, and niche segments such as shipbuilders and fuel suppliers were underrepresented, limiting the generalizability of findings.

Absence of a Functional Prototype

A major limitation is the lack of a live blockchain prototype. Although a system design was proposed in Chapter 3, the model remained conceptual. Attempts to simulate real-time data using platforms like MarineTraffic.com and AISHUB were hindered by cost and access restrictions. As a result, emissions tracking and smart contract functionalities were only demonstrated in theory, limiting validation of the system's practical feasibility, performance, and security in real-world maritime settings.[49]

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[49] *AIS data API (XML / JSON / CSV Webservice) | AISHub*. (n.d.). AISHub. https://www.aishub.net/api

Technical and Infrastructural Constraints

The study did not fully explore the implications of integrating blockchain with outdated maritime systems. Challenges such as interoperability gaps, cybersecurity risks, and lack of standardized data protocols were identified but not addressed through practical implementation. Limitations in hardware and connectivity, particularly in retrofitting older ships or ports, remain unresolved.

Regulatory and Legal Uncertainty

The absence of standardized international regulations for blockchain-based carbon credit systems is a significant constraint. While the study highlighted alignment needs with IMO and EU ETS policies, it did not analyse the legal complexities posed by immutable ledgers under data privacy laws like GDPR.

Narrow Emissions Scope

The focus was limited to carbon dioxide (CO_2) emissions. Other pollutants—such as sulphur oxides (SO_x), nitrogen oxides (NO_x), and black carbon—were not included, reducing the study's relevance to comprehensive maritime environmental compliance.

Economic Impact Not Fully Explored

Although the study suggests economic benefits like improved market access and lower compliance costs, it lacks a detailed cost-benefit analysis. High initial investments in infrastructure, training, and system upgrades—especially for small operators—were acknowledged but not quantified.

Time and Resource Constraints

Due to time and budget limitations, pilot testing and real-world system trials were not conducted. The reliance on secondary data and theoretical modelling further limits the applicability of the findings in operational environments.

5.5 Future Prospects

The maritime industry stands at a critical juncture, balancing its pivotal role in global trade with the urgent need to address its environmental impact. This study has demonstrated the transformative potential of blockchain technology in enhancing transparency, efficiency, and accountability in carbon emissions tracking and carbon credit trading. Looking ahead, several promising prospects emerge for the integration of blockchain in maritime decarbonization, offering opportunities to overcome current challenges and drive sustainable innovation.

One of the most significant future prospects is the development of scalable, interoperable blockchain platforms tailored for the maritime sector. As discussed in Chapter 3, permissioned blockchains like Hyperledger Fabric offer privacy, regulatory compliance, and scalability, making them ideal for integrating with existing maritime systems. Future advancements in blockchain interoperability will enable seamless data exchange across regional and global carbon markets, such as the EU ETS and voluntary registries. By developing standardized APIs and protocols, blockchain platforms can bridge fragmented systems, ensuring that carbon credits issued in one jurisdiction are recognized globally. This will enhance the credibility of carbon markets, encourage broader participation, and support the IMO's ambitious goal of reducing shipping emissions by 50% by 2050.

The integration of emerging technologies with blockchain presents another exciting avenue. The synergy of blockchain with IoT, AI, and satellite-based monitoring, as highlighted in Chapter 4, can enable near real-time emissions tracking with unprecedented accuracy. For instance, IoT-enabled shipboard sensors can feed data on fuel consumption, vessel speed, and environmental conditions directly into a blockchain ledger, while AI algorithms analyze this data to optimize emissions calculations. Satellite systems, like those used by platforms such as Coorest, can verify carbon sequestration projects, ensuring that credits represent genuine reductions. Future research should focus on piloting these integrated systems in real-world maritime operations, addressing technical barriers such as connectivity on older vessels and ensuring cybersecurity to protect sensitive data.

Smart contracts are poised to revolutionize regulatory compliance and carbon credit trading. As outlined in Chapter 3, smart contracts can automate credit issuance, retirement, and compliance verification, reducing administrative costs and eliminating fraud risks like double counting. In the future, smart contracts could be programmed to enforce dynamic carbon pricing based on real-time emissions data, creating a responsive market that incentivizes immediate reductions. Collaborative efforts between the IMO, national regulators, and tech developers will be crucial to establish legal frameworks that recognize smart contract-based transactions, ensuring their enforceability across jurisdictions.

Another prospect lies in expanding blockchain applications beyond CO_2 to encompass other pollutants, such as SO_x, NO_x, and black carbon. While this study focused on carbon emissions, a holistic blockchain-based system could track multiple pollutants, aligning with MARPOL Annex VI and other environmental regulations. This would require developing standardized metrics and verification processes for non-CO_2 emissions, leveraging IoT and blockchain to ensure comprehensive monitoring. Such systems could also support incentive programs, rewarding operators for adopting cleaner fuels or technologies like LNG, hydrogen, or wind-assisted propulsion.

Finally, blockchain's potential to foster stakeholder collaboration and innovation cannot be overstated. By creating decentralized marketplaces for carbon credits, blockchain can democratize access, enabling smaller operators and developing nations to participate in emissions reduction initiatives. Pilot projects, supported by global bodies like the IMO and industry consortia, can demonstrate blockchain's benefits, building trust and encouraging adoption. Additionally, blockchain's transparency can empower environmental organizations and consumers to hold the industry accountable, driving demand for sustainable shipping practices.

In summary, the future of blockchain in maritime decarbonization is bright, with prospects for scalable platforms, integrated technologies, automated compliance, comprehensive emissions tracking, and inclusive markets. Realizing these opportunities will require sustained investment, regulatory alignment, and industry collaboration to translate theoretical frameworks into practical, impactful solutions.

ANNEXURE

STAKEHOLDER SURVEY QUESTIONNAIRE

Likert: (1-5) Strongly Disagree to Strongly Agree

1. I am aware of What Blockchain Technology is. (Likert)
2. I understand the potential use of blockchain in monitoring maritime carbon emissions. (Likert)
3. Blockchain technology can improve transparency and accountability in emission reporting. (Likert)
4. Blockchain adoption in the maritime sector is likely to grow significantly in the next five years. (Likert)
5. Using blockchain for carbon credits can enhance trust among stakeholders. (Likert)
6. Rank the following challenges in adopting blockchain for carbon emission tracking in maritime (1=Most challenging)

Challenge	1	2	3	4	5
Technical Complexity	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of Regulatory Support	[ ]	[ ]	[ ]	[ ]	[ ]
Cost of Implementation	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of Awareness	[ ]	[ ]	[ ]	[ ]	[ ]
Resistance to Change	[ ]	[ ]	[ ]	[ ]	[ ]

7. Rank the following benefits of using blockchain for carbon emission tracking (1 = Most Beneficial):

Benefit	1	2	3	4	5
Real-time emission tracking	[ ]	[ ]	[ ]	[ ]	[ ]
Better Regulatory Compliance	[ ]	[ ]	[ ]	[ ]	[ ]
Immutable Data Records	[ ]	[ ]	[ ]	[ ]	[ ]
Enhanced Stake holder trust	[ ]	[ ]	[ ]	[ ]	[ ]
Easier Carbon Credit trading	[ ]	[ ]	[ ]	[ ]	[ ]

8. A port starts using blockchain for real-time emission monitoring. What impact would this have on your trust in their sustainability efforts?
    i. Much higher Trust
    ii. Slightly higher Trust
    iii. No Change
    iv. Less Trust
    v. Don’t know
9. If given the opportunity, how likely are you to support the implementation of blockchain for emission tracking in a maritime project?
    i. Very Likely
    ii. Likely
    iii. Neutral
    iv. Unlikely
    v. Very Unlikely
10. Imagine a situation where carbon credit fraud is discovered in maritime shipping. Do you think blockchain could have prevented it?
    i. Definitely
    ii. Probably
    iii. Not sure
    iv. Probably Not
    v. Definitely Not
11. The maritime industry is ready for digital solutions like blockchain to manage its environmental goals. (Likert)
12. Carbon credit systems integrated with blockchain will be more efficient than current systems. (Likert)
13. In your opinion, what is the biggest hurdle for blockchain adoption in maritime emissions tracking?
    i. Lack of Technical Expertise
    ii. No Clear Policy Framework
    iii. Cost of Infrastructure
    iv. Low Awareness
    v. Data Privacy Concerns
14. Do you believe blockchain can directly contribute to decarbonization efforts in maritime logistics? (Likert)

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DECLARATION

I, **ABEL P T**, **Reg. No. 2303304001** student of the **School of Maritime Management, Indian Maritime University**, pursuing an **MBA in Port and Shipping Management** hereby declare that this submission of this report **'Blockchain Enabled Carbon Credit System for Green Shipping'** has been prepared by me towards the partial fulfilment of the Master of Business Administration in Port & Shipping Management under the supervision of **Dr. B. Swaminathan** Associate Professor Head SMM, Indian Maritime University, Chennai Campus.

Place: Chennai

Date: 23/05/2025

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