BLOCKCHAIN-ENABLED CARBON TRANSPARENCY FOR MALAYSIA PORT-BASED LOGISTICS

BY

SYIMIR SYAHMI BIN TARIQ ASYRAF SHAH

Thesis Submitted to

College of Business

Universiti Utara Malaysia,

in Partial Fulfillment of the Requirement for the Master of Sciences (Management)

Kolej Perniagaan
(College of Business)
Universiti Utara Malaysia

PERAKUAN KERJA TESIS / DISERTASI
(Certification of thesis / dissertation)

Kami, yang bertandatangan, memperakukan bahawa
(We, the undersigned, certify that)

SYIMIR SYAHMI BIN TARIQ ASYRAF SHAH

calon untuk Ijazah
(candidate for the degree of) **MASTER OF SCIENCE (TRANSPORTATION & LOGISTICS MANAGEMENT)**

telah mengemukakan tesis / disertasi yang bertajuk:
(has presented his/her thesis / dissertation of the following title)

BLOCKCHAIN-ENABLED CARBON TRANSPARENCY FOR MALAYSIA PORT-BASED LOGISTICS

seperti yang tercatat di muka surat tajuk dan kulit tesis / disertasi.
(as it appears on the title page and front cover of the thesis / dissertation).

Bahawa tesis/disertasi tersebut boleh diterima dari segi bentuk serta kandungan dan meliputi bidang ilmu dengan memuaskan, sebagaimana yang ditunjukkan oleh calon dalam ujian lisan yang diadakan pada: **13 Januari 2026**.
(That the said thesis/dissertation is acceptable in form and content and displays a satisfactory knowledge of the field of study as demonstrated by the candidate through an oral examination held on: ***13 January 2026****.*

Pengerusi Viva *(Chairman for Viva)*	:	**Dr. Fariza Ahmad binti Mahyadin @ Mahidin**	Tandatangan *(Signature)*	
Pemeriksa Dalam *(Internal Examiner)*	:	**Dr. Fariza Ahmad binti Mahyadin @ Mahidin**	Tandatangan *(Signature)*	
Pemeriksa Dalam *(Internal Examiner)*	:	**Assoc. Prof. Ts. Dr. Nur Khairiel bin Anuar**	Tandatangan *(Signature)*	

Tarikh: **13 Januari 2026**
Date:

Nama Pelajar (Name of Student)	:	**Syimir Syahmi bin Tariq Asyraf Shah**
Tajuk Tesis / Disertasi *(Title of the Thesis / Dissertation)*	:	**Blockchain-Enabled Carbon Transparency for Malaysia Port-Based Logistics**
Program Pengajian *(Programme of Study)*	:	**Master of Science (Transportation & Logistics Management)**
Nama Penyelia/Penyelia-penyelia *(Name of Supervisor/Supervisors)*	:	**Dr. Izatul Husna binti Zakaria**
		Tandatangan
Nama Penyelia/Penyelia-penyelia *(Name of Supervisor/Supervisors)*	:	-
		Tandatangan

PERMISSION TO USE

(For Master By Coursework Candidate)

In presenting this dissertation/project paper in partial fulfillment of the requirements for a Post Graduate degree from the Universiti Utara Malaysia (UUM), I agree that the Library of this university may make it freely available for inspection. I further agree that permission for copying this dissertation/project paper in any manner, in whole or in part, for scholarly purposes may be granted by my supervisor(s) or in their absence, by the Director of Postgraduate Studies Unit, College of Business where I did my dissertation/project paper. It is understood that any copying or publication or use of this dissertation/project paper parts of it for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the UUM in any scholarly use which may be made of any material in my dissertation/project paper.

Request for permission to copy or to make other use of materials in this dissertation/project paper in whole or in part should be addressed to:

Director of Postgraduate Studies Unit, College of Business

Universiti Utara Malaysia

06010 UUM Sintok

Kedah Darul Aman

ABSTRACT

Global pressure to decarbonize maritime transport has intensified following the International Maritime Organization's (IMO) 2023 Greenhouse Gas (GHG) Strategy, which requires enhanced emissions transparency, reporting accuracy, and accountability across port-based logistics systems. However, many ports, particularly in developing maritime economies such as Malaysia, continue to rely on fragmented and non-standardized carbon reporting mechanisms, limiting their ability to support credible emissions measurement, reporting, and verification (MRV). In response, this study explores the potential role of blockchain technology as an enabling mechanism for carbon transparency within Malaysian maritime ports. Using a qualitative research design, semi-structured expert interviews were conducted with five key stakeholders representing port authorities, regulatory bodies, maritime logistics operators, and digital technology specialists. The interview data were analyzed thematically using NVivo 15 to identify recurring patterns related to carbon reporting challenges, blockchain capabilities, governance readiness, and implementation pathways. The findings reveal strong consensus that current carbon reporting practices lack trust, interoperability, and verification robustness, while blockchain is perceived as a complementary digital layer capable of enhancing data integrity, traceability, and multi-stakeholder trust rather than replacing existing systems. The study further highlights uneven digital readiness across ports, the critical role of government and port authority leadership, and the necessity of phased, pilot-based implementation strategies. By contextualizing blockchain-enabled carbon transparency within Malaysia's port governance landscape, this research contributes practical and policy-relevant insights for aligning national maritime decarbonization efforts with international climate commitments.

Keywords: Blockchain technology, Carbon transparency, Port-based logistics, IMO 2023 GHG Strategy, Malaysia

ABSTRAK

Tekanan global terhadap penyahkarbonan sektor maritim semakin meningkat susulan pengenalan Strategi Gas Rumah Hijau (GHG) 2023 oleh Pertubuhan Maritim Antarabangsa (IMO), yang menekankan keperluan terhadap ketelusan pelepasan karbon, ketepatan laporan, dan akauntabiliti dalam sistem logistik berasaskan pelabuhan. Walau bagaimanapun, kebanyakan pelabuhan, khususnya di negara maritim membangun seperti Malaysia, masih bergantung kepada mekanisme laporan karbon yang terpisah dan tidak diseragamkan, sekali gus menjejaskan keberkesanan pengukuran, laporan, dan pengesahan pelepasan karbon (MRV). Sehubungan itu, kajian ini bertujuan meneroka potensi teknologi rantaian blok (blockchain) sebagai mekanisme pemudah cara untuk meningkatkan ketelusan karbon dalam pelabuhan maritim di Malaysia. Reka bentuk kajian kualitatif digunakan melalui temu bual separa berstruktur dengan lima orang pakar yang mewakili pihak berkuasa pelabuhan, badan pengawalseliaan, pengendali logistik maritim, dan pakar teknologi digital. Data temu bual dianalisis secara tematik menggunakan perisian NVivo 15 bagi mengenal pasti corak berkaitan cabaran laporan karbon, keupayaan blockchain, tahap kesiapsiagaan tadbir urus, dan laluan pelaksanaan. Dapatan kajian menunjukkan persetujuan yang kukuh bahawa sistem pelaporan karbon sedia ada kekurangan aspek kepercayaan, kesepadanan sistem, dan kebolehpercayaan pengesahan, manakala blockchain dilihat sebagai lapisan digital pelengkap yang berupaya meningkatkan integriti data, kebolehkesanan, dan kepercayaan antara pihak berkepentingan tanpa menggantikan sistem sedia ada. Kajian ini turut menekankan perbezaan tahap kesiapsiagaan digital antara pelabuhan, peranan penting kepimpinan kerajaan dan pihak berkuasa pelabuhan, serta keperluan pendekatan pelaksanaan secara berperingkat dan berasaskan projek perintis. Dapatan kajian ini menyumbang kepada pemahaman kontekstual berkaitan usaha penyahkarbonan maritim Malaysia selaras dengan komitmen iklim antarabangsa.

Kata kunci: Teknologi blockchain, Ketelusan karbon, Logistik berasaskan pelabuhan, Strategi GHG IMO 2023, Malaysia

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to Allah SWT for His guidance, blessings, and strength throughout my educational journey. Without His will and continuous guidance, the completion of this postgraduate study would not have been possible. I am truly grateful for the opportunities and perseverance granted to me from the beginning of my academic journey until now and for what lies ahead in the future.

I would also like to extend my sincere appreciation to my family, who have always believed in me and supported me unconditionally throughout my postgraduate studies at Universiti Utara Malaysia. Their encouragement, understanding, and continuous prayers have been a constant source of motivation during this challenging yet rewarding journey.

My heartfelt gratitude goes to Universiti Utara Malaysia (UUM) and the School of Technology Management and Logistics (STML) for providing me with the opportunity to pursue my postgraduate studies in this prestigious institution. The academic environment, resources, and support provided by the university have contributed significantly to my learning and research development.

I would like to express my deepest thanks to my supervisor, Dr Izatul Husna Binti Zakaria, for her invaluable guidance, constructive feedback, and continuous support throughout the research process. Her willingness to share ideas, provide insightful suggestions, and dedicate her time to discussions and meetings has greatly enhanced the quality of this research and strengthened my academic understanding.

I am also sincerely grateful to the Paper Coordinator, Dr Rushanim, for her assistance and guidance throughout the technical aspects of the research paper completion and submission process. Her

patience in addressing my numerous questions and her clear explanations were extremely helpful in ensuring that all requirements were met successfully.

Finally, I would like to extend my appreciation to all individuals who have directly or indirectly contributed to the completion of this research. Their support and encouragement are deeply appreciated.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ADB - Asian Development Bank

AIS - Automatic Identification System

API - Application Programming Interface

ASEAN - Association of Southeast Asian Nations

CO_2 - Carbon Dioxide

CO_2e - Carbon Dioxide Equivalent

DWT - Deadweight Tonnage

GHG - Greenhouse Gas

GHG MRV - Greenhouse Gas Measurement, Reporting, and Verification

ICT - Information and Communication Technology

IEA - International Energy Agency

IMO - International Maritime Organization

IMO DCS - International Maritime Organization Data Collection System

IoT - Internet of Things

ISO - International Organization for Standardization

IT - Information Technology

KPI - Key Performance Indicator

MRV - Measurement, Reporting, and Verification

NGO - Non-Governmental Organization

NVivo - Qualitative Data Analysis Software (QSR NVivo)

OECD - Organization for Economic Co-operation and Development

RO - Research Objective

RQ - Research Question

SME - Small and Medium-sized Enterprise

STML - School of Technology Management and Logistics

TOS - Terminal Operating System

UN - United Nations

UNCTAD - United Nations Conference on Trade and Development

UNESCAP - United Nations Economic and Social Commission for Asia and the Pacific

UUM - Universiti Utara Malaysia

CHAPTER 1: INTRODUCTION

1.1 Background of Study

The maritime transport sector plays a central role in facilitating global trade, accounting for more than 80% of international trade by volume and approximately 70% by value (UNCTAD, 2023). While shipping is widely regarded as a comparatively energy-efficient mode of transport, its cumulative environmental impact is significant due to the scale and growth of global maritime activities. According to the International Maritime Organization (IMO), international shipping is responsible for approximately 2.8% of global greenhouse gas (GHG) emissions, a figure that is projected to increase if mitigation measures are not effectively implemented (IMO, 2023). This growing contribution has placed the maritime industry under increasing pressure from regulators, cargo owners, investors, and international bodies to improve emissions monitoring, reporting, and reduction practices.

Ports and port-based logistics systems occupy a critical position within the maritime value chain. Beyond serving as physical nodes for cargo handling, ports function as coordination hubs where shipping lines, terminal operators, logistics service providers, fuel suppliers, and regulatory agencies interact. As a result, ports are not only direct sources of emissions through cargo-handling equipment, energy consumption, and vessel operations at berth but also key enablers of decarbonization initiatives across maritime supply chains (Acciaro et al., 2022). Effective port-level governance and transparency mechanisms are therefore essential to achieving meaningful emissions reduction outcomes within the broader maritime ecosystem.

In recognition of the urgency of climate action, the IMO revised its Initial GHG Strategy in 2023, setting more ambitious targets for international shipping. The IMO 2023 GHG Strategy calls for a

reduction in the carbon intensity of international shipping by at least 40% by 2030 (compared to 2008 levels), and for net-zero GHG emissions "by or around 2050" (IMO, 2023). Central to achieving these targets is the establishment of robust systems for emissions measurement, reporting, and verification (MRV), which enable accurate tracking of emissions performance and support evidence-based policy interventions. However, the effectiveness of MRV systems depends heavily on the accuracy, consistency, and credibility of emissions data across multiple actors and jurisdictions.

Despite the existence of international frameworks such as the IMO Data Collection System (DCS) and regional mechanisms like the European Union's MRV regulation, persistent challenges remain in ensuring data transparency and trustworthiness within maritime logistics networks (Psaraftis et al., 2022). Emissions data are often fragmented across organizations, stored in incompatible systems, and subject to manual reporting processes that increase the risk of errors, inconsistencies, and disputes. These issues are particularly pronounced in port-based logistics environments, where multiple stakeholders generate, process, and rely on emissions-related data for regulatory compliance, operational decision-making, and sustainability reporting.

In developing maritime economies such as Malaysia, these challenges are further compounded by uneven digital maturity, variations in governance capacity, and differing levels of awareness regarding advanced emissions reporting technologies (UNESCAP, 2023). Malaysia's ports play a vital role in regional and global trade, serving as key gateways within Southeast Asia's maritime network. Major ports such as Port Klang, Port of Tanjung Pelepas, and Penang Port support extensive container, bulk, and transshipment activities, all of which contribute to port-related emissions (Ministry of Transport Malaysia, 2022). As Malaysia aligns its national policies with

international decarbonization agendas, there is a growing need to strengthen carbon transparency mechanisms within its maritime and port-based logistics sector.

Recent advances in digital technologies have prompted increasing interest in blockchain as a potential enabler of transparent and trustworthy sustainability reporting. Blockchain technology is characterized by decentralized data storage, immutability, and shared access among authorized participants, making it particularly attractive for applications requiring data integrity and auditability (Kouhizadeh et al., 2022). Within environmental and supply chain contexts, blockchain has been proposed as a mechanism to enhance traceability, prevent data manipulation, and facilitate trusted information sharing across organizational boundaries (Saberi et al., 2023). These features align closely with the requirements of carbon transparency and MRV systems, where confidence in reported data is critical for regulatory compliance and market credibility.

Within the maritime domain, emerging studies suggest that blockchain could support emissions reporting by acting as a verification layer that records fuel consumption, emissions calculations, and compliance-related data in a tamper-resistant manner (Perboli et al., 2023). However, much of the existing literature remains conceptual or focused on technologically advanced regions, with limited empirical insight into how blockchain-enabled carbon transparency might function in developing maritime contexts. There is a notable lack of research examining how blockchain adoption intersects with port governance structures, stakeholder readiness, and regulatory expectations in countries such as Malaysia.

Against this backdrop, this study seeks to explore the potential role of blockchain technology in enhancing carbon transparency within Malaysia's maritime and port-based logistics sector, with specific reference to alignment with the IMO 2023 GHG Strategy. By drawing on qualitative insights from industry experts, policymakers, and maritime stakeholders, the research aims to

provide context-specific understanding of the opportunities, challenges, and governance considerations associated with blockchain-enabled carbon reporting. In doing so, the study contributes to both academic discourse and practical policy development by addressing a critical gap between global decarbonization ambitions and local implementation realities.

1.2 Problem Statement

The global maritime industry is facing mounting pressure to decarbonize in response to climate change commitments and evolving regulatory requirements. Although international shipping is often described as a relatively low-carbon transport mode on a per-tonne-kilometre basis, its absolute greenhouse gas (GHG) emissions remain substantial due to the scale of global maritime trade. The International Maritime Organization (IMO) reported that GHG emissions from international shipping reached approximately 1,076 million tonnes of CO_2-equivalent in 2018, representing about 2.8% of global anthropogenic emissions (IMO, 2023). Without effective mitigation and monitoring mechanisms, these emissions are projected to increase by up to 50% by 2050 under a business-as-usual scenario (IMO, 2023). This has led to heightened regulatory scrutiny and the introduction of more stringent decarbonization targets under the IMO 2023 GHG Strategy.

A central challenge in achieving maritime decarbonization lies in the limited transparency, consistency, and credibility of carbon emissions data across maritime and port-based logistics systems. Current GHG reporting mechanisms, including the IMO Data Collection System (DCS), rely heavily on self-reported data submitted by shipping companies and related actors. While these systems represent an important step toward emissions accountability, several studies have identified persistent weaknesses, such as data fragmentation, inconsistent reporting practices, limited verification capabilities, and a lack of real-time data integration (Psaraftis et al., 2022; Tran

et al., 2023). These limitations undermine the reliability of emissions data and constrain policymakers' ability to design evidence-based interventions aligned with international climate goals.

Within port-based logistics environments, the problem is further exacerbated by the involvement of multiple stakeholders, including port authorities, terminal operators, shipping lines, logistics service providers, and regulatory agencies. Each stakeholder often operates separate information systems and reporting practices, resulting in siloed data structures that hinder comprehensive emissions visibility (Acciaro et al., 2022). As a result, disputes over data accuracy, responsibility allocation, and compliance status are common, particularly when emissions data are used for regulatory reporting, environmental performance benchmarking, or market-based measures. This lack of integrated and trusted data infrastructure represents a significant barrier to achieving carbon transparency at the port level.

In the Malaysian context, these challenges are especially pronounced. Malaysia's maritime sector is a critical contributor to national economic development, with ports handling more than 27 million TEUs annually and supporting extensive regional transshipment activities (Ministry of Transport Malaysia, 2022). However, existing carbon reporting practices within Malaysian ports remain largely fragmented and are not supported by a unified national framework for maritime emissions transparency (UNESCAP, 2023). While environmental initiatives and digitalization efforts are increasingly promoted at the policy level, the implementation of advanced emissions monitoring and verification systems remains uneven across ports and operators. This creates a gap between Malaysia's international climate commitments and the practical capability of its maritime sector to demonstrate transparent and credible emissions performance.

Blockchain technology has been widely proposed in recent literature as a potential solution to address data integrity and trust challenges in sustainability reporting. Its core characteristics such as immutability, decentralization, and shared access offer theoretical advantages for ensuring the reliability and auditability of emissions data across organizational boundaries (Kouhizadeh et al., 2022; Saberi et al., 2023). In the context of GHG management, blockchain-based systems have been suggested as tools to support measurement, reporting, and verification (MRV) processes by reducing data manipulation risks and enhancing traceability (Perboli et al., 2023). Despite these proposed benefits, empirical evidence on the practical application of blockchain for carbon transparency in maritime and port-based logistics remains limited.

More critically, existing studies have predominantly focused on technologically advanced economies or conceptual system designs, with insufficient attention given to governance readiness, institutional constraints, and stakeholder acceptance in developing maritime contexts. In Malaysia, where port governance structures, regulatory coordination, and digital maturity vary significantly, the feasibility and effectiveness of blockchain-enabled carbon transparency systems remain unclear. There is a lack of empirical research examining how blockchain aligns with existing port governance frameworks, how stakeholders perceive their role in emissions reporting, and what implementation pathways are most suitable for aligning with the IMO 2023 GHG Strategy.

Therefore, the core problem addressed in this study is the absence of a clear, empirically grounded understanding of how blockchain technology can support carbon transparency within Malaysia's maritime and port-based logistics sector in a manner that is operationally feasible, governance-aligned, and consistent with international decarbonization expectations. Without such understanding, policymakers, port authorities, and industry stakeholders risk adopting fragmented or misaligned digital solutions that fail to deliver meaningful emissions transparency or regulatory

compliance. This study seeks to address this gap by investigating expert perspectives on blockchain-enabled carbon reporting, identifying key challenges and readiness factors, and clarifying the governance mechanisms required to support effective implementation in the Malaysian maritime context.

1.3 Research Question

This study is guided by three core research questions, each addressing a specific dimension of blockchain-enabled carbon transparency in Malaysian port-based logistics, while remaining consistent with the IMO 2023 GHG Strategy and contemporary sustainability reporting literature.

RQ1:

What are the key challenges affecting carbon emissions reporting and transparency within Malaysian maritime ports and port-based logistics systems?

This question seeks to identify structural, operational, and governance-related issues that limit effective GHG measurement, reporting, and verification (MRV) in Malaysian ports. Prior studies indicate that fragmented data ownership, manual reporting practices, and lack of standardization are persistent barriers in maritime emissions reporting (Acciaro et al., 2022; Psaraftis et al., 2022). Addressing this question establishes the baseline problem that necessitates digital and governance-oriented interventions.

RQ2:

How do maritime and port-related experts perceive the role of blockchain technology in enhancing carbon transparency and emissions data integrity?

This question focuses on expert perceptions regarding blockchain's suitability as a technological mechanism for improving trust, traceability, and auditability of carbon emissions data. Existing literature highlights blockchain's theoretical advantages for sustainability reporting, yet empirical insights from developing maritime contexts remain limited (Kouhizadeh et al., 2022; Saberi et al., 2023). This research question enables the study to bridge the gap between conceptual propositions and practical stakeholder perspectives.

RQ3:

How governance, readiness, and implementation factors influence the adoption of blockchain-based carbon reporting systems in Malaysian maritime ports?

This question examines institutional readiness, organizational capacity, and policy-related factors that shape blockchain adoption pathways. Recent policy and academic literature emphasize that decentralized technologies still require coordinated governance frameworks, particularly in regulated sectors such as maritime transport (UNESCAP, 2023; World Bank, 2024). Addressing this question allows the study to identify realistic implementation conditions aligned with Malaysia's port governance structure and the IMO 2023 GHG Strategy.

1.4 Research Objective

The research objectives were refined to ensure clarity, feasibility, and full alignment with the qualitative nature of the study. The set of objectives was streamlined to avoid excessive breadth and ensure that each objective can be directly addressed through empirical findings. This study is guided by three core research objectives, each corresponding directly to one research question. This enables the findings and discussion to clearly demonstrate how the study has met its stated aims.

RO1:

To examine the key challenges affecting carbon emissions reporting and transparency within Malaysian maritime ports and port-based logistics systems.

This objective focuses on examining operational, structural, and governance-related barriers that hinder effective greenhouse gas (GHG) measurement, reporting, and verification (MRV) at the port level. Previous studies indicate that maritime emissions reporting is often constrained by fragmented data ownership, reliance on manual reporting practices, and the absence of harmonized reporting standards across stakeholders (Acciaro et al., 2022; Psaraftis et al., 2022). By addressing this objective, the study establishes a clear understanding of the existing problem landscape that necessitates digital and governance interventions.

RO2:

To explore expert perceptions of blockchain technology as a mechanism for enhancing carbon transparency and emissions data integrity in maritime ports.

The second objective seeks to understand how blockchain technology is perceived by maritime and port-related experts in relation to carbon transparency. While the literature highlights blockchain's theoretical potential to enhance trust, traceability, and auditability of sustainability data, empirical insights particularly from developing maritime economies remain limited (Kouhizadeh et al., 2022; Saberi et al., 2023).

This objective does not aim to evaluate blockchain performance technically, but rather to capture expert insights regarding its perceived suitability, limitations, and practical relevance for carbon reporting within port-based logistics systems. This aligns with the qualitative design of the study and ensures that findings remain grounded in stakeholder realities.

RO3:

To examine governance, readiness, and implementation factors influencing the adoption of blockchain-based carbon reporting systems in Malaysian maritime ports.

The third objective examines the broader institutional and organizational conditions that shape blockchain adoption pathways. Existing research emphasizes that successful implementation of digital technologies in ports depends not only on technical capability, but also on governance leadership, regulatory clarity, organizational readiness, and stakeholder collaboration (UNESCAP, 2023; World Bank, 2024).

By addressing this objective, the study seeks to identify realistic and context-specific adoption considerations, including readiness gaps across ports, resistance to change, and the role of government and port authorities in coordinating implementation efforts. This objective avoids proposing a technical solution and instead focuses on identifying enabling and constraining factors relevant to policy and practice.

1.5 Research Scope

This study is deliberately scoped to examine blockchain-enabled carbon transparency within Malaysian maritime ports and port-based logistics systems. The scope is defined across sectoral, technological, geographical, stakeholder, and methodological boundaries to ensure analytical depth, feasibility, and alignment with the research objectives.

1.5.1 Sectoral Scope: Maritime Ports and Port-Based Logistics

The study focuses specifically on the maritime port sector, rather than the broader transportation or logistics industry. This focus is justified on three grounds.

First, maritime transport is responsible for approximately 2–3% of global greenhouse gas (GHG) emissions, with ports acting as critical nodes where emissions from vessels, cargo handling equipment, and hinterland transport converge (IMO, 2023; UNCTAD, 2024). Ports therefore represent a strategic intervention point for emissions monitoring and transparency.

Second, ports play a governance and coordination role within maritime supply chains. Unlike shipping companies or logistics firms operating independently, ports interact simultaneously with regulators, shipping lines, terminal operators, bunker suppliers, and customs authorities. This multi-actor environment makes ports particularly relevant for studying carbon data integration and verification challenges (Acciaro et al., 2022; Psaraftis et al., 2022).

Third, Malaysia's major ports such as Port Klang and Penang Port are increasingly exposed to international decarbonization pressures, especially from trading partners aligned with the IMO 2023 GHG Strategy and emerging carbon disclosure requirements (IMO, 2023; World Bank, 2024). This positions Malaysian ports as suitable case environments for exploring carbon transparency mechanisms.

1.5.2 Technological Scope: Blockchain for Carbon MRV Support

The technological scope of this study is limited to blockchain as a digital enabler of carbon transparency, specifically within the context of measurement, reporting, and verification (MRV) processes.

The present study does not seek to design, develop, or empirically test a blockchain system. Rather, it adopts a conceptual and governance-oriented perspective by examining blockchain as a supporting technology for carbon transparency within port-based logistics and maritime operations. The focus of the analysis is on expert perceptions of blockchain's potential to enhance

data integrity and immutability, facilitate secure and transparent data sharing among multiple stakeholders, strengthen auditability and regulatory reporting processes, and complement existing port and maritime information systems. By concentrating on these governance and institutional dimensions, the study aims to provide insight into how blockchain could be strategically positioned to support emissions reporting and compliance objectives, rather than evaluating technical system performance or implementation outcomes

This scoped focus aligns with recent literature that positions blockchain as a verification layer, rather than a replacement for legacy systems in sustainability reporting contexts (Kouhizadeh et al., 2022; Perboli et al., 2023).

1.5.3 Carbon Emissions Scope

Figure 1 Carbon Emission Scope

Figure 1 explains the GHG Protocol classification of emissions, which provides a framework for measuring and reporting carbon emissions at the organizational or sectoral level. It highlights that

Scope 3 emissions often account for the largest share of total emissions, particularly in logistics, shipping, and port-based supply chains, making them more complex but critical to manage.

The study concentrates on operational carbon emissions associated with port-related maritime activities, which represent a significant and measurable component of emissions within the port ecosystem. Specifically, the scope includes vessel-related emissions generated while ships are at berth, fuel consumption and bunker delivery records linked to maritime operations, energy use from cargo handling equipment such as cranes and terminal machinery, and emissions arising from port infrastructure and facilities. Focusing on these emission sources allows the study to examine areas where data fragmentation and reporting challenges are most prominent and where blockchain-enabled transparency mechanisms could offer meaningful governance and reporting benefits.

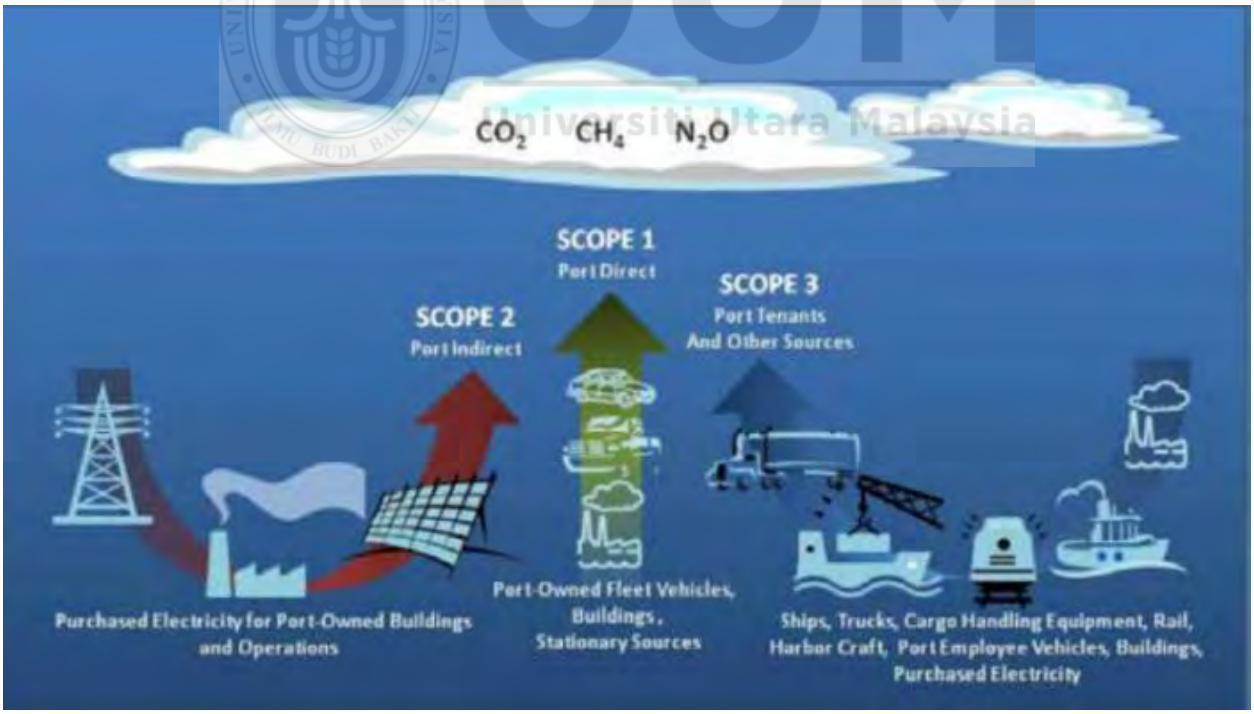

Figure 2 Port Carbon Emission Scope

Figure 2 illustrate how GHG emissions (CO_2, CH_4, N_2O) are generated within and around a port ecosystem, and how they are categorized into Scope 1, Scope 2, and Scope 3 from a port authority's perspective.

The scope aligns with Scope 1 and Scope 2 emissions, as commonly defined in port sustainability reporting frameworks, while recognizing that certain Scope 3 emissions may be discussed where relevant to transparency challenges (World Ports Sustainability Program, 2023).

The study does not attempt to calculate emissions quantitatively. Instead, it focuses on how emissions data are reported, verified, and governed, consistent with a qualitative research design.

1.5.4 Geographical Scope: Malaysia

Geographically, the study is confined to Malaysia's maritime and port governance context. This national focus is justified by Malaysia's strategic role in global maritime trade, particularly within major international shipping routes, as well as the presence of multiple large and internationally connected ports. In addition, Malaysia is currently pursuing national digitalization and sustainability initiatives that create a relevant policy environment for examining blockchain adoption. The study is further motivated by increasing regulatory alignment pressures stemming from Malaysia's obligations under the International Maritime Organization's greenhouse gas reduction framework, making the Malaysian context both timely and policy-relevant for this research.

While international standards such as the IMO 2023 GHG Strategy are discussed, they are examined only insofar as they influence Malaysian port governance and reporting practices. The study does not conduct cross-country comparisons or regional benchmarking, although references to ASEAN or global contexts are used for analytical grounding.

1.5.5 Stakeholder Scope

The empirical scope of the study is limited to expert stakeholders with direct involvement in maritime emissions governance, port operations, or digitalization initiatives. These include representatives from port authorities and port governance bodies, maritime regulators responsible for compliance and policy oversight, international shipping line representatives with operational exposure to emissions reporting requirements, and maritime digitalization consultants involved in the development or advisory aspects of digital systems within the port and shipping environment. The selection of these expert groups ensures that the findings are informed by practical experience and strategic insight relevant to blockchain-enabled carbon transparency in the maritime sector.

This expert-focused scope is consistent with qualitative research practices aimed at capturing strategic, policy-level, and operational insights, rather than general perceptions (Creswell & Poth, 2023).

1.5.6 Methodological Scope

Methodologically, the study adopts a qualitative structured interview approach based on structured and written expert interviews. NVivo 15 is used solely for thematic coding, pattern identification, and data organization.

This methodological boundary ensures coherence between the research objectives, data collection methods, and analytical techniques.

1.6 Significance of Study

This study makes significant contributions at theoretical, practical, policy, and methodological levels by addressing an emerging but underexplored intersection between blockchain technology, carbon transparency, and maritime port governance in Malaysia. By focusing on port-based

logistics within the context of the IMO 2023 Greenhouse Gas (GHG) Strategy, the study responds directly to contemporary sustainability challenges facing the global maritime sector.

1.6.1 Theoretical Significance

From a theoretical perspective, this study extends existing literature on blockchain and sustainability by contextualizing blockchain-enabled carbon transparency within port governance structures, rather than treating blockchain purely as a technical innovation. While prior studies have examined blockchain adoption in supply chains broadly, fewer have explored its role in carbon measurement, reporting, and verification (MRV) within maritime ports, particularly in developing or emerging maritime economies (Kouhizadeh et al., 2022; Saberi et al., 2023).

Furthermore, this study contributes to institutional and governance-based perspectives on digital sustainability by demonstrating that decentralized technologies such as blockchain still rely on centralized coordination, regulatory legitimacy, and institutional leadership. This finding reinforces recent arguments that technology adoption in sustainability contexts cannot be understood independently of governance and organizational readiness (Perboli et al., 2023; Psaraftis et al., 2022).

By integrating blockchain theory with maritime decarbonization discourse, the study provides a conceptual bridge between digital transformation research and environmental governance literature, thereby enriching both domains.

1.6.2 Practical Significance for Industry Stakeholders

Practically, the study offers valuable insights for port authorities, shipping lines, terminal operators, and logistics service providers seeking to enhance carbon transparency in response to growing international market and regulatory pressures.

The findings highlight that blockchain is perceived by industry experts not as a disruptive replacement technology, but as a verification and trust-enabling mechanism that can complement existing digital systems. This practical positioning is important, as resistance to blockchain adoption is often driven by fears of system replacement, cost escalation, and operational disruption (Treiblmaier, 2022; Perboli et al., 2023).

By identifying specific operational challenges such as fragmented data ownership, manual reporting practices, and lack of standardization, the study provides industry stakeholders with clear guidance on where blockchain-enabled solutions may add value, particularly in improving auditability, data integrity, and stakeholder confidence in emissions reporting.

1.6.3 Policy and Regulatory Significance

At the policy level, this study contributes to ongoing discussions on how national maritime authorities can operate international climate commitments. The findings underscore the absence of a nationally standardized carbon reporting framework for Malaysian ports, a gap that has also been highlighted in recent global policy assessments (IMO, 2023; World Bank, 2024).

The study provides empirical support for the argument that government leadership and regulatory clarity are essential for enabling blockchain adoption in carbon reporting. This includes the development of reporting standards, data governance rules, and regulatory sandboxes that allow controlled experimentation with emerging technologies.

For policymakers, the study offers evidence-based justification for integrating blockchain into broader maritime decarbonization strategies, aligning national port governance practices with evolving international expectations under the IMO 2023 GHG Strategy.

1.6.4 Methodological Significance

Methodologically, this study demonstrates the value of a qualitative, expert-driven approach in exploring emerging technological applications where empirical implementation remains limited. By employing structured expert interviews and thematic analysis supported by NVivo 15, the study captures strategic, regulatory, and operational insights that are not easily observable through quantitative methods alone (Creswell & Poth, 2023).

The use of NVivo 15 as an analytical support tool enhances transparency, rigor, and traceability in the coding and interpretation process, addressing common criticisms related to subjectivity in qualitative research. The study thus contributes to methodological best practices in maritime and sustainability research, particularly for exploratory studies involving complex governance and digitalization issues.

1.6.5 Societal and Environmental Significance

Finally, the study has broader societal relevance by contributing to efforts aimed at improving accountability and transparency in maritime decarbonization. Transparent and credible emissions reporting is a foundational requirement for achieving meaningful reductions in GHG emissions and for maintaining public and stakeholder trust in sustainability initiatives (UNCTAD, 2024; World Ports Sustainability Program, 2023).

By examining how blockchain could support these objectives within Malaysian ports, the study aligns with national and global sustainability agendas, reinforcing the role of maritime governance in addressing climate change challenges.

1.7 Organization of Research Paper

This research paper is organized into five main chapters, each designed to systematically address the research objectives and research questions while ensuring logical progression from conceptual grounding to empirical analysis and discussion.

Chapter 1: Introduction

Chapter 1 introduces the research by outlining the background and context of blockchain-enabled carbon transparency within Malaysia's maritime and port-based logistics sector. It presents the problem statement, research questions, research objectives, scope of the study, and the significance of the research. This chapter establishes the rationale for the study and highlights its relevance in relation to international decarbonization initiatives, particularly the IMO 2023 Greenhouse Gas (GHG) Strategy.

Chapter 2: Literature Review and Research Framework

Chapter 2 critically reviews existing literature related to greenhouse gas emissions in maritime transport, blockchain technology fundamentals, blockchain applications in environmental sustainability, and carbon measurement, reporting, and verification (MRV) systems. The chapter also examines strategic management and policy perspectives relevant to port governance and digital transformation. Based on identified research gaps, a conceptual research framework is developed to guide empirical investigation.

Chapter 3: Research Methodology

Chapter 3 explains the research design and methodological approach adopted in this study. It details the qualitative research philosophy, data collection methods, population and sampling strategy, interview instrument development, and data analysis procedures using NVivo 15. Ethical considerations and strategies to ensure research rigor and trustworthiness are also discussed.

Chapter 4: Findings and Analysis

Chapter 4 presents the empirical findings derived from expert interviews. Using thematic analysis supported by NVivo 15, the chapter systematically reports key themes and sub-themes that emerged from the data. The findings are explicitly linked to the research questions and research objectives, with supporting tables, figures, and excerpts from expert responses to enhance analytical transparency.

Chapter 5: Discussion, Implications, and Conclusion

Chapter 5 discusses the findings in relation to the literature reviewed in Chapter 2, highlighting theoretical, practical, and policy implications. The chapter synthesizes how the findings contribute to existing knowledge on blockchain-enabled carbon transparency and maritime decarbonization. It also outlines recommendations for policymakers, port authorities, and industry stakeholders, and concludes the study by summarizing key insights and identifying directions for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Greenhouse Gas Emissions and Climate Strategy in Maritime Transport

The maritime transport sector plays a critical role in facilitating global trade, yet it is also a significant contributor to greenhouse gas (GHG) emissions. According to the International Maritime Organization (IMO), international shipping accounts for approximately 2.8–3.0% of global anthropogenic CO_2 emissions, a figure projected to increase substantially if no effective mitigation measures are implemented (IMO, 2023). As global supply chains expand and trade volumes increase, maritime emissions have become a focal point in international climate policy discussions, particularly in relation to hard-to-abate sectors.

Recognizing the environmental impact of shipping activities, the IMO has progressively strengthened its climate governance framework. The most recent and comprehensive initiative is the IMO 2023 Revised Greenhouse Gas Strategy, which establishes a long-term vision for achieving net-zero GHG emissions from international shipping by or around 2050, with interim checkpoints for 2030 and 2040 (IMO, 2023). These targets mark a significant escalation in ambition compared to the previous 2018 strategy and signal a shift from voluntary environmental commitments toward enforceable climate accountability.

A core pillar of the IMO's climate strategy is the emphasis on measurement, reporting, and verification (MRV) of emissions data. Effective decarbonization policies rely heavily on accurate, transparent, and standardized emissions data to enable monitoring of progress, enforcement of regulations, and benchmarking across operators and jurisdictions (Psaraftis, 2023). However, existing maritime emissions reporting mechanisms such as the IMO Data Collection System (DCS) and the EU Monitoring, Reporting and Verification (EU MRV) framework have been

criticized for inconsistencies, limited interoperability, and challenges in data reliability, particularly when extended across port-based logistics activities (Chen et al., 2024).

In the context of port-based logistics, emissions are not generated solely by vessel operations at sea but also by a wide range of onshore activities, including cargo handling equipment, terminal operations, port infrastructure, trucking, and auxiliary energy use. Recent studies highlight that port-related emissions can represent a substantial share of total maritime logistics emissions, yet these emissions are often fragmented across multiple actors and systems, making comprehensive reporting difficult (UNESCAP, 2023). This fragmentation creates significant barriers to achieving end-to-end carbon transparency across maritime supply chains.

From a strategic perspective, climate action in maritime transport is no longer driven exclusively by environmental considerations but is increasingly shaped by market pressure, regulatory compliance, and competitive positioning. Shipping lines and port operators are facing growing demands from cargo owners, financiers, and insurers to disclose credible emissions data as part of environmental, social, and governance (ESG) reporting requirements (OECD, 2024). Failure to provide transparent and verifiable emissions information may result in reduced access to green financing, reputational risks, and potential exclusion from environmentally sensitive trade routes.

For port authorities, particularly in developing and emerging maritime economies such as Malaysia, aligning national port operations with international climate strategies presents both challenges and opportunities. While ports are not directly regulated under IMO conventions in the same manner as vessels, they play a crucial enabling role in supporting compliance through data provision, infrastructure readiness, and governance coordination (World Bank, 2024). Consequently, ports are increasingly recognized as critical nodes in the implementation of maritime decarbonization strategies.

Despite the growing importance of carbon transparency, the literature consistently identifies gaps between international climate ambitions and on-the-ground implementation, especially in developing maritime contexts. These gaps are often attributed to limited digital readiness, lack of standardized reporting frameworks, fragmented data ownership, and insufficient coordination among stakeholders (Zhen et al., 2022; UNESCAP, 2023). As a result, there is increasing scholarly interest in exploring digital technologies that can support transparent, trustworthy, and scalable emissions reporting systems.

Within this evolving policy and operational landscape, blockchain technology has emerged as a potential enabler of enhanced carbon transparency and governance. However, before examining blockchain's role, it is essential to establish a clear understanding of the emissions challenge and the strategic climate frameworks governing maritime transport. This section therefore provides the foundational context for subsequent discussions on blockchain technology, carbon MRV systems, and governance mechanisms in later sections of this chapter.

2.2 Blockchain Technology: Concepts and Fundamental Characteristics

Blockchain technology has emerged as a foundational digital innovation capable of transforming how data are recorded, shared, and governed across complex multi-actor systems. Originally conceptualized as the underlying architecture for cryptocurrencies, blockchain has since evolved into a broader digital infrastructure with applications extending into supply chain management, sustainability governance, public administration, and environmental reporting (Treiblmaier, 2022). At its core, blockchain is a distributed ledger technology (DLT) that enables the decentralized recording of transactions across a network of participants without reliance on a single central authority.

A blockchain operates by grouping transactions into blocks, which are cryptographically linked to previous blocks, forming an immutable chain of records. Once validated through a consensus mechanism, each block is added permanently to the ledger and replicated across all participating nodes in the network. This architecture ensures that records cannot be altered retroactively without detection, thereby enhancing data integrity and trust among participants (Perboli et al., 2023). In contrast to traditional centralized databases, blockchain systems distribute control and verification responsibilities across multiple actors, reducing single points of failure and opportunities for data manipulation.

One of the most fundamental characteristics of blockchain is immutability. Immutability refers to the practical impossibility of altering recorded data once they have been validated and stored on the ledger. This feature is particularly relevant in contexts where data credibility, auditability, and regulatory compliance are critical, such as financial reporting, supply chain traceability, and environmental disclosure (Kouhizadeh et al., 2022). In sustainability and emissions reporting, immutability addresses long-standing concerns regarding data tampering, selective disclosure, and post-hoc modification of records.

Another defining characteristic of blockchain is transparency with controlled access. While public blockchains allow open access to transaction data, enterprise and permissioned blockchains more commonly proposed for industrial and regulatory applications enable role-based access control. This allows sensitive operational data to remain confidential while still providing regulators and authorized stakeholders with verifiable and auditable records (Saberi et al., 2023). Such flexibility makes blockchain particularly suitable for regulated sectors like maritime transport, where commercial sensitivity and compliance requirements must be carefully balanced.

Decentralization is also a key conceptual feature of blockchain systems. Decentralization does not imply the absence of governance but rather a redistribution of data validation and control across network participants. In practical applications, especially within logistics and port systems, blockchain networks are often governed by a consortium model in which selected stakeholders such as port authorities, regulators, and industry operators jointly manage system rules and access rights (Treiblmaier et al., 2023). This hybrid governance structure allows blockchain systems to align with existing institutional frameworks while retaining their technical advantages.

Closely related to decentralization is the concept of consensus mechanisms, which determine how transactions are validated and agreed upon within the network. Unlike energy-intensive proof-of-work mechanisms used in early public blockchains, enterprise applications typically adopt more efficient consensus models such as Practical Byzantine Fault Tolerance (PBFT) or Proof-of-Authority (PoA). These mechanisms are particularly suitable for port and logistics environments, where participants are known entities and energy efficiency is a priority (Perboli et al., 2023).

Blockchain systems can also support smart contracts, which are self-executing digital agreements embedded within the blockchain. Smart contracts automatically trigger predefined actions when specified conditions are met, reducing reliance on manual processes and intermediaries. In sustainability governance, smart contracts have been proposed for automating emissions reporting, compliance checks, and verification workflows (Chen et al., 2024). However, the effectiveness of smart contracts depends heavily on the accuracy and reliability of input data, often referred to as the “oracle problem,” which remains a recognized limitation in blockchain implementation.

Despite its technical potential, the literature cautions against viewing blockchain as a standalone or universal solution. Recent studies emphasize that blockchain should be understood as an enabling infrastructure that complements existing digital systems rather than replacing them

entirely (Treiblmaier, 2022). Successful adoption depends not only on technological readiness but also on organizational capacity, governance alignment, regulatory clarity, and stakeholder collaboration. Without these supporting conditions, blockchain initiatives risk becoming fragmented pilot projects with limited long-term impact.

In the context of maritime transport and port-based logistics, these fundamental characteristics include immutability, transparency, decentralization, and auditability align closely with the requirements of carbon measurement, reporting, and verification systems. However, the translation of blockchain's theoretical benefits into practical environmental governance outcomes remains an empirical question. This gap between conceptual promise and real-world implementation provides the foundation for examining blockchain's role in environmental sustainability and GHG management in subsequent sections of this chapter.

2.3 Blockchain Applications in Environmental Sustainability

In recent years, blockchain technology has gained increasing attention as a digital enabler for environmental sustainability initiatives across multiple sectors. Beyond its origins in financial transactions, blockchain is now being explored as a governance-support tool capable of improving transparency, accountability, and coordination in sustainability-related activities. Literature increasingly positions blockchain as a mechanism that can address persistent environmental governance challenges, particularly those related to data fragmentation, trust deficits, and verification inefficiencies (Saberi et al., 2023; Treiblmaier et al., 2023).

One of the most prominent sustainability-related applications of blockchain lies in environmental data management and traceability. Environmental reporting systems traditionally rely on centralized databases, self-reported data, and manual verification processes, which are vulnerable

to errors, manipulation, and inconsistencies. Blockchain's decentralized ledger structure allows environmental data such as emissions records, energy consumption, and resource usage to be recorded in a tamper-resistant manner, providing a verifiable audit trail accessible to authorized stakeholders (Kouhizadeh et al., 2022). This capability is particularly valuable in sustainability contexts where data credibility directly influences regulatory compliance, market reputation, and stakeholder trust.

Blockchain has also been widely discussed in the context of carbon management and emissions disclosure systems. Recent studies highlight its potential role in improving the reliability of carbon accounting processes by ensuring that emissions data are recorded consistently and transparently across organizational boundaries (Upadhyay et al., 2023). In supply chain environments, where emissions are generated by multiple actors operating under different reporting standards, blockchain can function as a shared infrastructure that consolidates data without requiring full centralization. This feature aligns closely with emerging regulatory expectations for end-to-end emissions visibility across logistics and transport networks.

Another significant area of application concerns carbon markets and emissions trading mechanisms. Blockchain-based platforms have been proposed to enhance the integrity of carbon credit issuance, tracking, and retirement by preventing double counting and unauthorized reuse of credits (Chen et al., 2024). Through immutable record-keeping and real-time verification, blockchain can strengthen trust in carbon markets, which have historically faced credibility challenges due to opaque verification processes and inconsistent standards. While this application is more commonly discussed in energy and industrial sectors, the underlying principles are increasingly relevant to maritime transport as international pressure for market-based emissions reduction mechanisms intensifies.

Beyond emissions-specific use cases, blockchain is also being applied to broader environmental governance and sustainability reporting frameworks. Scholars argue that blockchain can support Environmental, Social, and Governance (ESG) reporting by enabling standardized, auditable, and time-stamped disclosure of sustainability indicators (Rejeb et al., 2023). In this context, blockchain does not replace existing reporting frameworks but enhances their credibility by strengthening data provenance and traceability. This perspective reinforces the view that blockchain's primary sustainability value lies in governance support rather than direct emissions reduction.

In the logistics and transport sectors, blockchain-enabled sustainability applications often focus on supply chain transparency and coordination. Transport-related emissions are inherently multi-actor in nature, involving ports, shipping lines, terminal operators, freight forwarders, and inland transport providers. Traditional sustainability initiatives struggle to capture emissions across these interconnected activities due to siloed data systems and competing commercial interests. Blockchain has been proposed as a neutral digital layer that facilitates trusted data sharing without forcing stakeholders to relinquish full control over proprietary information (Treiblmaier, 2022). This capability is particularly relevant for port-based logistics systems, where public and private actors must collaborate within a regulated environment.

Despite its growing adoption, literature also highlights several limitations and risks associated with blockchain-based sustainability applications. Technical challenges include data input reliability, system interoperability, scalability, and cybersecurity concerns. From an organizational perspective, studies report resistance stemming from limited digital maturity, unclear cost–benefit structures, and uncertainty regarding regulatory acceptance (Perboli et al., 2023). These challenges suggest that blockchain's sustainability benefits are highly contingent on governance design, stakeholder alignment, and institutional readiness.

Importantly, recent research emphasizes that blockchain should be viewed as an enabling infrastructure rather than a sustainability solution in itself. Blockchain does not reduce emissions directly; instead, it supports improved decision-making, accountability, and compliance by enhancing the quality and credibility of environmental information (Upadhyay et al., 2023). This distinction is critical in avoiding technological determinism and ensuring realistic expectations among policymakers and industry practitioners.

Within the maritime context, the application of blockchain for environmental sustainability remains an emerging research area. While studies have explored blockchain in shipping documentation, cargo tracking, and port digitalization, its role in supporting greenhouse gas measurement, reporting, and verification (MRV) systems is less empirically examined, particularly in developing and emerging maritime economies such as Malaysia. This gap underscores the need for context-specific research that examines how blockchain-enabled sustainability applications interact with existing governance structures, regulatory expectations, and operational realities in port-based logistics systems.

2.4 Blockchain for Greenhouse Gas Measurement, Reporting, and Verification (MRV)

Measurement, Reporting, and Verification (MRV) systems form the backbone of effective greenhouse gas (GHG) governance across transport, logistics, and maritime sectors. MRV frameworks are designed to ensure that emissions data are measured accurately, reported consistently, and verified credibly to support regulatory compliance, policy evaluation, and market-based mechanisms. In the maritime sector, MRV has become increasingly important following international regulatory developments such as the IMO Data Collection System (DCS) and the IMO 2023 Greenhouse Gas Strategy, which demand progressively higher levels of transparency and accountability (IMO, 2023).

Despite their importance, existing GHG MRV systems face persistent structural and operational challenges. Literature consistently highlights issues related to fragmented data sources, manual reporting processes, inconsistent methodologies, and limited verification capacity, particularly in complex, multi-actor systems such as port-based logistics chains (UNCTAD, 2023). In maritime logistics, emissions data are generated by multiple stakeholders, including shipping lines, terminal operators, port authorities, bunker suppliers, and inland transport providers. The absence of a unified data infrastructure often results in inconsistent reporting, delayed submissions, and difficulties in cross-checking emissions information across organizational boundaries.

Blockchain technology has emerged in recent literature as a potential digital enabler for strengthening GHG MRV systems. From a measurement perspective, blockchain can function as a trusted data registry that records emissions-related inputs such as fuel consumption, energy use, and operational activity data in an immutable and time-stamped manner (Upadhyay et al., 2023). When integrated with existing data collection systems, blockchain can enhance data traceability by preserving a verifiable chain of custody from the point of data generation to regulatory reporting.

In the reporting phase, blockchain-based MRV systems can improve consistency and transparency by standardizing how emissions data are submitted and shared among authorized stakeholders. Rather than relying on siloed databases maintained by individual organizations, blockchain enables the creation of a shared ledger that supports harmonized reporting formats while respecting access permissions (Kouhizadeh et al., 2022). This capability is particularly relevant in maritime contexts, where reporting obligations increasingly extend beyond national regulators to include international bodies, cargo owners, and sustainability-conscious customers.

Verification represents one of the most critical weaknesses in traditional MRV systems, as it often depends on retrospective audits, manual document checks, and selective sampling. Recent studies argue that blockchain can enhance verification processes by enabling near real-time auditability and reducing reliance on trust-based assumptions (Saberi et al., 2023). Because records stored on blockchain cannot be altered retroactively without consensus, verifiers can focus on assessing data quality and methodological compliance rather than authenticity alone. This shift has the potential to reduce verification costs while improving confidence in reported emissions data.

In the context of maritime transport, blockchain-enabled MRV is increasingly discussed as a complementary mechanism to existing international reporting schemes rather than a replacement. Scholars emphasize that blockchain should support, not substitute, established frameworks such as the IMO DCS or national port-level emissions inventories (Perboli et al., 2023). This complementary role is especially important given the regulatory sensitivity of emissions data and the need for alignment with internationally recognized standards.

Another emerging application of blockchain in GHG MRV relates to cross-border emissions accountability. Maritime emissions often occur outside national jurisdictions, complicating responsibility allocation and reporting oversight. Blockchain's decentralized architecture allows multiple regulators and stakeholders to access consistent emissions records without requiring a single controlling authority, potentially improving transparency in international shipping routes (Rejeb et al., 2023). This feature aligns with the IMO's emphasis on global coordination and shared responsibility for maritime decarbonization.

However, the literature also cautions that blockchain-enabled MRV systems are not without limitations. One recurring concern relates to the reliability of input data, commonly referred to as the "garbage in, garbage out" problem. Blockchain can preserve data integrity after entry, but it

does not inherently guarantee that initial measurements are accurate or unbiased (Treiblmaier et al., 2023). As such, blockchain-based MRV systems must be supported by robust measurement protocols, sensor calibration, and organizational controls to ensure data quality at the source.

Institutional readiness and governance design are also critical determinants of successful blockchain adoption in MRV systems. Studies highlight that without clear regulatory guidance, standardized methodologies, and defined authority roles, blockchain initiatives risk fragmentation or underutilization (World Bank, 2024). In port-based logistics environments, where public and private actors coexist under varying regulatory obligations, governance clarity is particularly important to ensure participation and long-term system sustainability.

Within the Malaysian maritime context, empirical research on blockchain-enabled GHG MRV remains limited. While national sustainability policies increasingly emphasize emissions transparency and digital transformation, the operational integration of blockchain into maritime MRV systems has not been systematically examined. This gap is significant given Malaysia's strategic position as a regional maritime hub and its growing exposure to international decarbonization pressures. Consequently, this study positions blockchain-enabled MRV as a governance-support mechanism that warrants in-depth qualitative exploration grounded in local institutional and operational realities.

2.5 Strategic Management, Policy, and Governance Perspectives on Blockchain-Enabled Maritime Decarbonization

The adoption of blockchain technology for greenhouse gas (GHG) transparency in maritime and port-based logistics cannot be understood solely through a technological lens. Recent literature increasingly emphasizes that digital solutions for sustainability are shaped by strategic

management decisions, policy frameworks, and governance structures that influence how technologies are adopted, coordinated, and institutionalized (Bai et al., 2023). In the maritime sector, where operations span public and private actors across national and international jurisdictions, governance considerations play a particularly critical role.

From a strategic management perspective, carbon transparency has evolved from a voluntary corporate responsibility initiative into a strategic imperative linked to competitiveness, risk management, and long-term resilience. Shipping lines and ports are now evaluated not only on operational efficiency but also on their ability to demonstrate credible emissions accountability to regulators, customers, and investors (Acciaro et al., 2022). Studies highlight that ports with advanced sustainability governance structures are better positioned to attract green shipping services, secure financing, and align with global trade partners' environmental expectations.

Blockchain technology is increasingly discussed as a strategic enabler within this context rather than as a standalone innovation. Scholars argue that its value lies in supporting coordination across fragmented maritime ecosystems by enabling shared data governance mechanisms (Kouhizadeh et al., 2022). However, strategic alignment is required to ensure that blockchain initiatives support organizational objectives rather than introduce parallel systems that increase complexity. This requires clear leadership, cross-organizational collaboration, and alignment with broader digitalization strategies at the port and national levels.

Policy frameworks play a decisive role in shaping the feasibility and direction of blockchain adoption for carbon transparency. Internationally, maritime decarbonization policies such as the IMO 2023 GHG Strategy establish overarching targets and expectations but leave implementation details to national authorities and industry stakeholders (IMO, 2023). This policy design places significant responsibility on national governments and port authorities to translate global

commitments into operational reporting systems, enforcement mechanisms, and technological standards.

The literature highlights a recurring governance gap between international climate ambitions and local implementation capacity. While regulatory pressure for emissions transparency is increasing, many ports particularly in developing and emerging economies lack clear national guidelines on how digital technologies should be integrated into carbon reporting systems (UNESCAP, 2023). In the absence of explicit policy direction, organizations may hesitate to invest in blockchain solutions due to regulatory uncertainty, data ownership concerns, and unclear compliance implications.

Governance scholars emphasize that blockchain adoption in regulated sectors requires hybrid governance models that combine decentralized technological features with centralized oversight (Treiblmaier et al., 2023). In maritime contexts, this typically involves regulatory bodies defining reporting standards and access rights, while operational stakeholders contribute data within a shared digital infrastructure. Such arrangements challenge traditional hierarchical governance models and require careful institutional design to balance transparency, accountability, and confidentiality.

Port authorities are increasingly positioned in the literature as key governance intermediaries in maritime decarbonization initiatives. As entities that interface between regulators, operators, and service providers, port authorities are well-placed to coordinate digital sustainability initiatives, host shared platforms, and facilitate stakeholder participation (Acciaro & McKinnon, 2023). Several studies argue that port-led digital governance models are more effective than fragmented, firm-level approaches when addressing system-wide challenges such as emissions reporting and data integration.

Another important policy consideration concerns the alignment of blockchain initiatives with national digital transformation and sustainability agendas. Research indicates that blockchain projects are more likely to succeed when embedded within broader policy frameworks that support data standardization, cybersecurity, and digital capacity-building (World Bank, 2024). Isolated pilot projects without policy backing often struggle to scale or sustain stakeholder engagement over time.

Risk governance is also a prominent theme in recent literature. While blockchain offers enhanced transparency and auditability, it introduces new risks related to cybersecurity, data privacy, and system interoperability. Policymakers must therefore consider not only technological benefits but also risk mitigation mechanisms, including access controls, legal accountability frameworks, and contingency planning (Rejeb et al., 2023). These concerns are particularly salient in maritime logistics, where commercially sensitive data and national security considerations coexist.

In the Malaysian context, strategic and governance considerations are especially important given the country's ambition to position itself as a regional maritime and logistics hub. While Malaysia has articulated national commitments to emissions reduction and digital innovation, empirical research examining how governance structures support or constrain blockchain-enabled carbon transparency in ports remains limited. Existing studies tend to focus on technological potential without sufficiently examining institutional readiness, authority roles, and policy coherence.

This gap highlights the need for research that integrates strategic management, policy, and governance perspectives when evaluating blockchain adoption for maritime carbon transparency. By examining expert insights from regulatory, operational, and industry stakeholders, this study seeks to contribute context-specific understanding of how governance arrangements can either

enable or hinder the effective use of blockchain as a tool for GHG transparency in Malaysian port-based logistics.

2.6 Challenges, Risks, and Limitations of Blockchain Adoption for GHG Transparency in Maritime Logistics

Despite the growing interest in blockchain as an enabler of carbon transparency, recent literature consistently cautions that its adoption in maritime and port-based logistics is accompanied by significant challenges, risks, and structural limitations. Understanding these constraints is critical to avoid overly deterministic assumptions about blockchain's transformative potential and to ensure that technological solutions are aligned with operational realities and governance capacities.

One of the most frequently cited challenges is technological complexity and system interoperability. Ports and maritime operators typically operate heterogeneous legacy systems developed over extended periods to support terminal operations, vessel traffic management, customs clearance, and logistics coordination. Integrating blockchain platforms with these existing systems requires robust application programming interfaces (APIs), data standardization protocols, and cybersecurity safeguards, which are often lacking in port environments (Baryannis et al., 2023). Without interoperability, blockchain risks becoming an isolated system rather than a unifying infrastructure for emissions data.

Closely related is the issue of data quality and reliability at the point of entry. Blockchain ensures immutability after data is recorded, but it does not guarantee the accuracy of data input. Several studies emphasize the "garbage in, garbage out" problem, whereby inaccurate or manipulated emissions data entered into a blockchain ledger remain permanently stored, undermining trust

rather than enhancing it (Saberi et al., 2023). This limitation is particularly relevant in GHG reporting contexts, where emissions calculations often rely on estimates, proxies, or self-reported data.

Cost and resource constraints represent another major barrier, especially for smaller ports and logistics operators. Blockchain implementation involves not only software development but also investments in digital infrastructure, staff training, system maintenance, and governance mechanisms. Research indicates that while large ports and multinational shipping lines may possess the financial and technical capacity to experiment with blockchain, smaller stakeholders often lack the resources required for meaningful participation (UNESCAP, 2023). This uneven adoption risks reinforcing existing power asymmetries within maritime supply chains.

From an organizational perspective, resistance to change and limited digital literacy pose significant non-technical barriers. Studies show that employees and managers may perceive blockchain as complex, disruptive, or threatening due to increased transparency and perceived loss of control over data (Rejeb et al., 2023). In the absence of targeted training and change management strategies, such resistance can slow adoption and limit the effectiveness of pilot initiatives.

Governance and regulatory uncertainty further complicate blockchain adoption for carbon transparency. While international frameworks such as the IMO 2023 GHG Strategy emphasize emissions monitoring and reporting, they do not prescribe specific digital technologies or data architectures (IMO, 2023). At the national level, the absence of clear regulatory guidelines regarding blockchain use, data ownership, legal accountability, and compliance obligations creates uncertainty for organizations considering investment in blockchain-based reporting systems

(World Bank, 2024). This uncertainty is particularly pronounced in regulated sectors such as ports, where compliance risks carry significant operational and financial consequences.

Data privacy and confidentiality risks are also prominent in the literature. Maritime emissions data may reveal commercially sensitive information related to fuel consumption, operational efficiency, and competitive positioning. While blockchain can enhance transparency, excessive openness may conflict with commercial interests and data protection regulations. Scholars argue that permissioned blockchain models with clearly defined access controls are more appropriate for maritime applications, but these models require sophisticated governance arrangements to balance transparency and confidentiality (Treiblmaier et al., 2023).

Cybersecurity risks represent an additional concern. Although blockchain itself is often described as secure, vulnerabilities may arise from smart contracts, user interfaces, and integration points with external systems. Ports, as critical infrastructure, are increasingly targeted by cyber threats, making cybersecurity governance a critical consideration in any blockchain-based solution (Baryannis et al., 2023).

Finally, the literature highlights the risk of pilot project stagnation. Many blockchain initiatives remain confined to small-scale pilots that fail to transition into operational systems due to lack of institutional support, unclear value propositions, or insufficient stakeholder participation (Perboli et al., 2023). This pattern underscores the importance of aligning blockchain projects with strategic objectives, regulatory frameworks, and long-term funding mechanisms.

In the Malaysian maritime context, these challenges are amplified by varying levels of digital maturity across ports, fragmented governance structures, and limited empirical evidence on blockchain deployment for environmental reporting. While policy ambitions related to

digitalization and sustainability exist, the translation of these ambitions into coordinated, scalable blockchain initiatives remains uncertain. These limitations highlight the need for context-specific research that examines not only technological feasibility but also institutional readiness, governance capacity, and stakeholder dynamics.

By critically examining these challenges and risks, this study positions blockchain not as a universal solution but as a conditional enabler whose effectiveness depends on strategic alignment, governance design, and collective participation. This balanced perspective provides a necessary foundation for identifying research gaps and developing a conceptual framework in the subsequent sections.

2.7 Research Gaps and Problem Synthesis

The preceding review of literature demonstrates substantial academic and policy interest in greenhouse gas (GHG) emissions reduction, blockchain technology, and digital transformation within logistics and supply chain systems. However, despite this growing body of knowledge, several critical gaps remain unresolved, particularly when examined through the lens of maritime and port-based logistics in emerging economies such as Malaysia.

First, while international climate strategies such as the IMO 2023 GHG Strategy emphasize the importance of accurate emissions monitoring, reporting, and verification (MRV), existing studies predominantly focus on regulatory targets and technological options, rather than on how emissions data are operationalized, shared, and governed at the port level. Most empirical research concentrates on shipping companies or global supply chains, leaving ports key nodes in maritime logistics underexplored as active facilitators of carbon transparency (IMO, 2023; UNCTAD,

2024). This creates a gap in understanding how port-based logistics systems can practically support emissions accountability across multiple stakeholders.

Second, although blockchain has been widely proposed as a solution for sustainability reporting and data integrity, much of the existing literature remains conceptual or experimental in nature. Systematic reviews highlight that many blockchain studies rely on theoretical models, simulations, or single-firm case studies, with limited empirical validation involving real-world stakeholders (Rejeb et al., 2023; Saberi et al., 2023). There is a notable lack of qualitative evidence capturing expert perceptions, governance concerns, and implementation realities within regulated maritime environments.

Third, studies addressing blockchain-enabled carbon transparency often adopt a technology-centric perspective, assuming that technical feasibility will naturally translate into adoption. However, recent research increasingly argues that blockchain outcomes are shaped by institutional readiness, governance structures, and stakeholder coordination, rather than by technology alone (Treiblmaier et al., 2023). Despite this recognition, few studies empirically examine how these socio-institutional factors influence blockchain adoption for GHG reporting in ports, particularly in developing and middle-income economies.

Fourth, the majority of blockchain and sustainability studies are concentrated in European and East Asian contexts, where digital infrastructure, regulatory frameworks, and sustainability governance are relatively mature. Comparative reports suggest that ASEAN ports, including those in Malaysia, face unique challenges related to fragmented governance, uneven digital maturity, and limited integration between national climate policy and port operations (UNESCAP, 2023; World Bank, 2024). This geographic imbalance results in a contextual gap, limiting the applicability of existing findings to the Malaysian maritime sector.

Fifth, while prior studies acknowledge the importance of MRV systems for emissions management, there is limited exploration of blockchain as a verification and trust-enhancing layer, rather than as a replacement for existing systems. Recent industry-oriented research suggests that blockchain's value lies in strengthening auditability and data confidence, yet this nuanced positioning remains underexplored in academic literature (Perboli et al., 2023). This gap is particularly relevant for ports, where compliance, accountability, and stakeholder trust are central concerns.

Finally, there is an evident lack of integrated research frameworks that connect climate policy objectives, digital technology adoption, governance mechanisms, and organizational readiness within a single analytical model. Many studies address these dimensions in isolation, resulting in fragmented insights that do not adequately inform implementation pathways. The absence of such integrative frameworks limits the ability of policymakers and port authorities to translate theoretical potential into actionable strategies.

In response to these gaps, this study adopts a qualitative, expert-driven approach to explore how blockchain technology could support enhanced carbon transparency within Malaysian maritime ports. By focusing on governance structures, stakeholder readiness, and implementation pathways, the study seeks to move beyond technological determinism and contribute context-specific insights aligned with international decarbonization expectations such as the IMO 2023 GHG Strategy. This gap-driven focus provides a clear rationale for the development of the conceptual framework presented in the subsequent section.

2.8 Conceptual Framework and Theoretical Underpinning

This study is underpinned by an integrated theoretical perspective that combines Institutional Theory, Socio-Technical Systems Theory, and Technology Readiness perspectives to explain the adoption of blockchain-enabled carbon transparency within Malaysian maritime and port-based logistics. The integration of these theories is necessary to capture the complex interaction between regulatory pressure, technological capability, organizational readiness, and governance structures identified in the preceding literature.

2.8.1 Institutional Theory

Institutional Theory provides a foundational lens for understanding why organizations adopt sustainability-oriented technologies in response to external pressures rather than purely internal efficiency motivations. According to DiMaggio and Powell's institutional framework, organizational behavior is shaped by coercive, normative, and mimetic pressures. In the context of maritime decarbonization, coercive pressures arise from international regulations such as the IMO 2023 GHG Strategy, while normative pressures stem from industry expectations and stakeholder demands for transparency (DiMaggio & Powell, 1983; Scott, 2014).

Recent sustainability research confirms that environmental reporting practices in logistics and shipping are increasingly driven by regulatory alignment and legitimacy-seeking behavior rather than voluntary innovation alone (Kumar et al., 2023; UNCTAD, 2024). This theory is particularly relevant to Malaysian ports, where compliance with international maritime standards is critical for maintaining global trade competitiveness. Institutional Theory therefore explains why carbon transparency has become a strategic imperative, forming the external driver within the proposed framework.

2.8.2 Socio-Technical Systems Theory

While Institutional Theory explains external pressure, it does not fully capture the internal dynamics of technology adoption. Socio-Technical Systems Theory addresses this limitation by emphasizing that successful digital transformation depends on the alignment between technology, people, processes, and organizational structures (Geels, 2004).

Recent studies on blockchain adoption caution against viewing blockchain as a purely technical solution, highlighting that outcomes depend on governance design, stakeholder coordination, and trust relationships (Treiblmaier et al., 2023; Rejeb et al., 2023). In port-based logistics, where multiple actors operate under shared infrastructure, socio-technical alignment is essential to ensure interoperability and data credibility. This theory therefore explains how blockchain functions as a verification and trust-enhancing layer, rather than as a standalone replacement system.

2.8.3 Technology Readiness Perspective

To further explain variations in adoption capacity, this study incorporates a technology readiness perspective at the organizational and sectoral levels. Technology readiness reflects the availability of digital infrastructure, data management capabilities, human capital, and organizational willingness to adopt new systems (Parasuraman, 2000; UNESCAP, 2023).

Empirical evidence from ASEAN ports demonstrates uneven digital maturity across operators, resulting in fragmented adoption outcomes (World Bank, 2024). Integrating technology readiness into the framework allows the study to account for differences between ports and stakeholders, explaining why blockchain adoption is feasible in principle but constrained in practice. This perspective directly informs the study's focus on phased and pilot-based implementation pathways.

2.8.4 Proposed Conceptual Research Framework

Drawing on the above theoretical foundations, this study proposes a conceptual framework that explains blockchain-enabled carbon transparency as an outcome of interacting institutional, technological, and governance factors within the maritime logistics ecosystem.

At the macro level, international climate strategies (e.g., IMO 2023 GHG Strategy) and market pressures act as institutional drivers influencing national regulators and port authorities.

At the meso level, governance structures, policy coordination, and stakeholder collaboration shape how blockchain initiatives are designed and implemented.

At the micro level, organizational readiness, digital capability, and perceptions of blockchain determine adoption feasibility and operational integration.

Within this framework, blockchain is positioned as a carbon data verification and trust mechanism that supports Measurement, Reporting, and Verification (MRV) processes rather than replacing existing reporting systems. The effectiveness of blockchain-enabled carbon transparency is therefore contingent upon governance leadership, stakeholder participation, and digital readiness.

This conceptual framework directly informs:

- The formulation of the revised research questions and objectives,
- The qualitative methodology adopted in Chapter 3,
- The thematic analysis structure in Chapter 4, and
- Discussion of implementation pathways in Chapter 5.

2.9 Summary of Literature Review

This chapter has critically reviewed the literature on greenhouse gas (GHG) emissions management, international maritime climate strategies, blockchain technology fundamentals, and blockchain applications for environmental sustainability and carbon transparency. The review demonstrates that while global maritime decarbonization agendas particularly the IMO 2023 GHG Strategy have intensified pressure for accurate carbon measurement, reporting, and verification (MRV), existing port-based reporting systems remain fragmented, non-standardized, and largely trust-dependent (IMO, 2023; UNCTAD, 2024).

The literature further reveals that blockchain technology has been widely proposed as a mechanism to enhance data integrity, traceability, and trust in sustainability reporting. However, most existing studies focus on conceptual or technical blockchain architectures, with limited empirical investigation into real-world governance readiness, stakeholder perceptions, and institutional constraints particularly within developing and emerging maritime economies such as Malaysia (Rejeb et al., 2023; Treiblmaier et al., 2023). This highlights a clear empirical and contextual research gap.

Moreover, the review identifies that blockchain adoption in environmental reporting cannot be adequately explained through a purely technological lens. Institutional Theory explains how regulatory and market pressures drive organizational responses to carbon transparency demands, while Socio-Technical Systems Theory emphasizes the importance of aligning technology with governance structures, organizational processes, and human actors (DiMaggio & Powell, 1983; Geels, 2004). The inclusion of technology readiness perspectives further explains the uneven adoption capacity observed across ports and logistics stakeholders (Parasuraman, 2000; World Bank, 2024).

Despite these insights, the literature lacks an integrated framework that combines regulatory pressure, governance mechanisms, technological capability, and stakeholder readiness to explain how blockchain-enabled carbon transparency can be realistically implemented in port-based logistics systems. This gap is particularly evident in the Malaysian maritime context, where national carbon governance frameworks for ports remain underdeveloped and empirically underexplored (UNESCAP, 2023).

In response to these gaps, this study adopts a qualitative research approach to capture in-depth insights from domain experts directly involved in maritime operations, port governance, sustainability management, and digital systems. A qualitative design is appropriate because the research seeks to explore perceptions, readiness, governance challenges, and implementation pathways rather than to test predefined hypotheses (Creswell & Poth, 2018). Semi-structured interviews allow flexibility in probing expert interpretations of blockchain's role in carbon transparency while maintaining alignment with the research questions and objectives.

Thematic analysis is employed to systematically analyze interview data, enabling the identification of recurring patterns and themes that reflect institutional pressures, technological considerations, governance issues, and readiness barriers. This approach ensures analytical rigor while allowing theory-informed interpretation grounded in empirical evidence (Braun & Clarke, 2021). The conceptual framework developed in Section 2.8 directly informs the design of interview questions, coding structure, and interpretation of findings in subsequent chapters.

In summary, this literature review establishes a strong theoretical and empirical foundation for the study and provides clear justification for the qualitative methodology adopted in Chapter 3. By linking institutional drivers, socio-technical dynamics, and readiness considerations, the review

positions this research to make meaningful theoretical, practical, and policy contributions to blockchain-enabled carbon transparency in Malaysian maritime ports.

Based on the critical review of recent literature, this study identifies three key research gaps in relation to blockchain-enabled carbon transparency within the maritime and port-based logistics context. First, although existing studies have extensively discussed blockchain applications for sustainability and supply chain transparency, majority of this literature remains conceptual or technology-driven, with limited empirical investigation into how blockchain could support greenhouse gas (GHG) measurement, reporting, and verification (MRV) specifically within port-based maritime operations, particularly in developing or emerging maritime economies. Second, there is a notable lack of research that examines blockchain adoption from a governance and institutional perspective, including the roles of regulators, port authorities, and multi-stakeholder coordination mechanisms, despite the recognition that regulatory alignment and governance structures are critical for effective carbon reporting. Third, the existing body of literature provides limited context-specific insights for Malaysia, even though the country plays a strategic role in global maritime trade and is subject to increasing alignment pressures arising from the International Maritime Organization's decarbonization strategies, including the IMO 2023 GHG Strategy.

In response to these identified gaps, this study intends to contribute by providing empirical, context-specific insights into the potential role of blockchain as a governance-supporting mechanism for carbon transparency in Malaysian maritime ports. Through qualitative expert interviews, the study explores stakeholder perceptions of blockchain's capacity to enhance data integrity, auditability, and multi-stakeholder data sharing in support of maritime GHG reporting. By situating the analysis within Malaysia's port governance and regulatory environment, the study

addresses the need for locally grounded evidence while also contributing to broader theoretical and policy discussions on blockchain-enabled sustainability governance in the maritime sector.

CHAPTER 3: METHODOLOGY

3.1 Research Design and Approach

This study adopts a qualitative research design to explore the role of blockchain technology in enhancing carbon transparency within Malaysian maritime ports and port-based logistics systems. A qualitative approach is particularly appropriate given the exploratory nature of the research, the complexity of governance and technological adoption issues, and the limited empirical evidence available in the Malaysian maritime context. Rather than measuring predefined variables, this study seeks to understand how key stakeholders perceive carbon transparency challenges, blockchain applicability, and implementation readiness, which requires rich, contextual insights.

The research is grounded in an interpretivist research paradigm, which assumes that organizational practices, policy responses, and technology adoption decisions are socially constructed through stakeholder interactions and institutional contexts. Carbon reporting practices and blockchain adoption are influenced not only by technical feasibility but also by regulatory expectations, organizational culture, power relations, and professional experience. Interpretivism therefore provides an appropriate philosophical foundation for examining these phenomena within the maritime sector (Creswell & Poth, 2018).

Consistent with the conceptual framework developed in Chapter 2, the research design integrates institutional pressures, socio-technical dynamics, and technology readiness considerations. This integration necessitates direct engagement with individuals who are actively involved in maritime governance, port operations, sustainability management, and digitalization initiatives. As such, the study employs expert interviews as the primary data collection method. Expert interviews are

widely used in logistics, policy, and sustainability research where the objective is to capture informed perspectives on emerging or complex issues (Bogner et al., 2018).

The study adopts a structured qualitative interview approach, supported by written responses, to ensure consistency across participants while accommodating the professional constraints of senior maritime stakeholders. A structured format allows the research to systematically address the research questions and objectives while enabling experts to elaborate based on their institutional roles and experiences. This approach enhances comparability across responses without sacrificing depth.

In alignment with qualitative best practices, the research does not aim for statistical generalization. Instead, it seeks analytical generalization, whereby insights derived from expert perspectives are interpreted in relation to existing theories and literature (Yin, 2018). This approach is particularly suitable for policy- and governance-oriented research, where understanding mechanisms and contextual conditions is more valuable than quantifying prevalence.

Qualitative design is further justified by the study's focus on governance readiness, implementation barriers, and strategic pathways, which are not readily observable through secondary data or quantitative indicators. By eliciting expert interpretations, the study is able to uncover institutional constraints, coordination challenges, and perceptions of risk that shape blockchain adoption outcomes in practice.

Overall, the research design is intentionally aligned with the study's objectives, conceptual framework, and identified research gaps. The qualitative, interpretivist approach provides a robust methodological foundation for examining blockchain-enabled carbon transparency as a socio-

technical and governance-driven phenomenon within Malaysia's maritime and port-based logistics sector.

3.2 Research Strategy and Interview Design

This study employs a qualitative expert interview strategy as the primary research strategy to investigate blockchain-enabled carbon transparency within Malaysian maritime and port-based logistics. The choice of an expert interview strategy is justified by the specialized and policy-driven nature of the research topic, which requires insights from individuals possessing advanced professional knowledge, decision-making authority, or technical expertise related to maritime operations, port governance, sustainability reporting, and digital systems.

Expert interviews are particularly suitable for exploratory research in emerging technological and regulatory domains where empirical evidence remains limited and where institutional and governance factors play a critical role (Bogner et al., 2018). In the context of this study, blockchain adoption for greenhouse gas (GHG) transparency involves complex interactions between regulatory requirements, organizational readiness, and multi-stakeholder coordination. Such complexity cannot be adequately captured through surveys or secondary data alone, thereby necessitating in-depth qualitative inquiry.

A structured interview design was adopted to ensure consistency across expert responses and to maintain alignment with the research objectives and conceptual framework. The structured format involved a predefined set of interview questions that were asked uniformly to all participants. This approach facilitated systematic comparison of expert perspectives while reducing interviewer bias and enhancing methodological transparency (Saunders et al., 2019).

The interview questions were explicitly developed to reflect the five key dimensions identified in the conceptual framework:

(1) the importance of carbon transparency in maritime logistics,

(2) existing challenges in GHG reporting,

(3) the perceived role of blockchain technology,

(4) readiness and adoption barriers, and

(5) governance and implementation pathways.

Each dimension corresponds directly to the revised research questions and objectives, ensuring coherence between literature, methodology, and analysis.

Given the seniority and professional commitments of the selected experts, the interviews were conducted using a hybrid written-response approach with limited interactive clarification. Initially, a structured interview guide containing twenty open-ended questions was distributed to participants. Experts were given sufficient time to provide detailed written responses, allowing for reflection on technical and policy-related issues. Where necessary, follow-up clarification was conducted via email or short discussions to ensure accuracy and completeness of responses.

This written-response approach is recognized in qualitative research as appropriate when engaging with elite or expert participants who may have limited availability but possess valuable experiential knowledge (Meuser & Nagel, 2009). Moreover, written responses can enhance data quality by enabling respondents to articulate carefully considered views, particularly on complex governance and technological issues.

To support analytical rigor, reflective notes were maintained throughout the data collection process. These notes documented contextual observations such as emphasis, certainty, and caution expressed in expert responses. Such reflexive documentation supports interpretive depth during the thematic analysis stage and strengthens the credibility of qualitative findings (Braun & Clarke, 2021).

Overall, the research strategy and interview design were deliberately structured to balance methodological consistency with practical feasibility. This approach ensured that expert insights were systematically captured while remaining sensitive to the institutional context and professional constraints of participants within the Malaysian maritime sector.

3.3 Population and Sampling Strategy

The population for this study comprises key stakeholders involved in Malaysia's maritime and port-based logistics ecosystem who possess direct knowledge of greenhouse gas (GHG) emissions management, port governance, sustainability reporting, and maritime digitalization. Given the specialized nature of blockchain-enabled carbon transparency and its governance implications, the study does not target a broad population of maritime workers but instead focuses on experts with strategic, regulatory, or technical responsibilities related to the research phenomenon.

A purposive (judgemental) sampling strategy was adopted to identify participants who could provide informed and relevant insights aligned with the research objectives. Purposive sampling is widely used in qualitative research where the aim is to gain depth of understanding from information-rich cases rather than statistical representativeness (Patton, 2015). This approach is particularly appropriate for expert-based studies in policy, governance, and emerging technology contexts (Etikan et al., 2016).

Five experts were selected based on three key criteria:

(1) Professional role and decision-making authority within the maritime or port-related domain;

(2) Direct involvement in areas related to port governance, sustainability, regulation, logistics operations, or maritime digitalization; and

(3) Practical exposure to carbon reporting, environmental compliance, or digital systems within the maritime sector.

The selected experts represent diverse yet complementary stakeholder groups, ensuring a balanced range of perspectives across the maritime ecosystem. Below are the experts profile:

Table 3.1 Experts Profile

Expert Code	Role / Position	Years of Professional Experience	Area of Expertise / Field
Expert 1	Port-Related Governance Expert	15+ Years	Maritime Governance, Sustainability Policy, National Port Strategy
Expert 2	Port Authority Representative	10+ Years	Port Operations, Emissions Management, Port Administration
Expert 3	Maritime Digitalization Consultant	12+ Years	Blockchain Technology, Digital System Integration, Maritime IT Solutions
Expert 4	Senior Logistics Manager (International Shipping Line)	14+ Years	Shipping Operations, Regulatory Compliance, Carbon Reporting

Expert 5	Regulatory Officer, Marine Department Malaysia	18+ Years	Maritime Regulation, Environmental Compliance, Enforcement

The sample size of five experts is justified by the study's qualitative and exploratory nature. Qualitative research prioritizes information richness and conceptual saturation rather than numerical adequacy. Prior methodological literature indicates that expert studies can achieve meaningful analytical insights with a small number of carefully selected participants when the research scope is focused and the participants possess high levels of expertise (Guest et al., 2012; Hennink & Kaiser, 2022).

Moreover, the study adopts analytical generalization, whereby findings are interpreted in relation to theory and existing literature rather than extrapolated statistically to a wider population (Yin, 2018). The diversity of institutional roles represented among the experts enhances the credibility and transferability of the findings, as it allows cross-comparison of perspectives across regulatory, operational, and technological domains.

In summary, the population and sampling strategy were intentionally designed to ensure methodological rigor, relevance, and depth. By selecting a small but highly informed group of experts, the study can generate nuanced insights into the governance, readiness, and implementation dynamics of blockchain-enabled carbon transparency in Malaysian maritime ports.

3.4 Data Collection Procedure

The data collection process for this study followed a systematic, step-by-step qualitative procedure designed to ensure consistency, credibility, and transparency. The procedure was aligned with established qualitative research protocols and tailored to the professional context of senior maritime and port-sector experts.

Step 1: Identification and Invitation of Experts

Following the purposive sampling strategy outlined in Section 3.3, potential experts were identified through professional networks, institutional affiliations, and publicly available role descriptions within Malaysia's maritime ecosystem. Each prospective participant was contacted formally via email and provided with an invitation letter explaining the purpose of the study, the relevance of their expertise, and the voluntary nature of participation.

An information sheet was attached to the invitation, outlining the research objectives, expected time commitment, confidentiality measures, and data usage. This step ensured informed participation and aligned with ethical best practices in qualitative research (Saunders et al., 2019).

Step 2: Distribution of Interview Instrument

Once consent was obtained, participants were provided with a structured interview guide consisting of twenty open-ended questions. The questions were grouped into five thematic sections reflecting the conceptual framework developed in Chapter 2:

- Importance of carbon transparency in maritime logistics
- Current challenges in GHG reporting and data transparency
- Perceived role of blockchain technology

- Readiness and adoption barriers
- Governance and implementation pathways

The use of open-ended questions allowed participants to elaborate based on their institutional roles and professional experience, while the structured format ensured alignment with the research questions and objectives (Creswell & Poth, 2018).

Step 3: Written Responses and Clarification

Given the seniority and scheduling constraints of the participants, data collection was conducted primarily through written responses. Participants were given adequate time to reflect on the questions and provide detailed, considered answers. This approach is recognized as appropriate for expert and elite interviews, particularly when topics involve policy interpretation, governance judgment, and technical complexity (Bogner et al., 2018).

Where responses required clarification or elaboration, follow-up questions were communicated via email or short discussions. These clarifications were documented and treated as part of the original interview data, ensuring completeness and accuracy.

Step 4: Data Documentation and Preparation

All written responses and clarification notes were compiled into individual interview transcripts for each expert. Each transcript was anonymized using role-based identifiers (e.g., Expert 1: Port Governance; Expert 2: Port Authority) to protect participant confidentiality while preserving analytical clarity.

The transcripts were reviewed multiple times to ensure data accuracy and familiarity prior to analysis. This process of repeated reading is a recognized preparatory step in qualitative research, supporting immersion and reflexivity (Braun & Clarke, 2021).

Step 5: Data Storage and Management

All interview data were stored securely in password-protected digital folders accessible only to the researcher. Data management procedures complied with ethical research standards and ensured that information was used exclusively for academic purposes. Following preparation, the finalized transcripts were imported into NVivo 15 for systematic coding and analysis, as detailed in Section 3.6.

In summary, the data collection procedure was carefully designed to balance methodological rigor with practical feasibility. By employing a structured yet flexible approach, the study ensured that expert insights were captured comprehensively while maintaining alignment with ethical, analytical, and institutional research standards.

3.5 Development of Research Instrument

The research instrument for this study consisted of a structured qualitative interview guide comprising twenty open-ended questions, designed to elicit expert insights on blockchain-enabled carbon transparency within Malaysia's maritime and port-based logistics sector. The development of the interview instrument followed a systematic and theory-informed process, ensuring alignment with the research objectives, research questions, and conceptual framework established in Chapter 2.

3.5.1 Instrument Development Approach

The interview questions were developed using an adapt-and-adopt approach, whereby concepts and thematic areas from prior studies were adapted to the Malaysian maritime context rather than directly replicated. This approach is consistent with qualitative research best practices, which emphasize contextual relevance over strict replication of instruments originally designed for different sectors or regions (Saunders et al., 2019).

The instrument development process was guided by three primary sources:

- Contemporary literature on maritime decarbonization and GHG management, particularly studies addressing emissions reporting, regulatory pressure, and compliance in shipping and port operations.
- Blockchain and sustainability research, focusing on transparency, traceability, data integrity, and multi-stakeholder coordination.
- Policy and governance frameworks, including the IMO 2023 GHG Strategy and international guidance on carbon measurement, reporting, and verification (MRV).

Drawing on these sources ensured that the instrument captured both theoretical constructs and practical governance considerations relevant to the study.

3.5.2 Structure of the Interview Instrument

The interview guide was structured into five thematic sections, each corresponding directly to a component of the conceptual framework and revised research objectives:

Section A: Importance of Carbon Transparency

Questions explored expert perceptions of why carbon transparency has become critical in maritime and port-based logistics, including international market pressure and regulatory alignment.

Section B: Current Challenges in Carbon Reporting

This section examined operational, organizational, and technical barriers affecting GHG data collection, reporting accuracy, and standardization.

Section C: Role of Blockchain Technology

Questions focused on perceived benefits of blockchain, including data integrity, transparency, auditability, and its suitability for carbon MRV systems.

Section D: Readiness and Adoption Barriers

This section investigated institutional readiness, digital maturity, legacy systems, and organizational resistance to blockchain adoption.

Section E: Governance and Implementation Pathways

Questions explored policy leadership, regulatory frameworks, stakeholder coordination, and the feasibility of pilot-based and phased implementation strategies.

Each question was designed to be open-ended to encourage detailed explanations and allow experts to draw on their professional experiences. Open-ended questioning is particularly effective in expert interviews, as it facilitates the emergence of nuanced insights beyond predefined categories (Creswell & Poth, 2018).

3.5.3 Instrument Validation and Refinement

Prior to data collection, the interview instrument was reviewed to ensure content validity, clarity, and relevance. The review process involved checking each question against the research objectives and conceptual framework to confirm alignment and eliminate redundancy. Questions were refined to avoid ambiguity and ensure that each addressed a single concept, responding directly to examiner concerns regarding overlapping aims within research questions.

Although formal pilot testing was not conducted due to the limited availability of expert participants, the structured nature of the instrument and its grounding in established literature provided sufficient methodological robustness for qualitative inquiry (Braun & Clarke, 2021).

In summary, the research instrument was carefully developed through a structured, literature-informed process. By adopting and adapting established theoretical constructs to the Malaysian maritime context, the interview guide ensured methodological rigor, conceptual clarity, and strong alignment with the study's overall research design.

3.6 Data Analysis Procedure Using NVivo 15

The qualitative data collected from expert interviews were analyzed using thematic analysis, supported by NVivo 15 qualitative data analysis software. NVivo was employed as a systematic analytical tool to organize, code, visualize, and interrogate the data, rather than as a substitute for researcher interpretation. This approach aligns with best practices in qualitative research, where software supports analytical transparency and rigor while maintaining researcher reflexivity (Braun & Clarke, 2021).

3.6.1 Rationale for Using NVivo 15

NVivo 15 was selected due to its capacity to manage complex qualitative datasets, support hierarchical coding structures, and generate analytical visualizations such as node hierarchies, coding matrices, and comparison diagrams. These functions are particularly valuable for expert-based studies involving multi-dimensional themes such as governance, technology adoption, and sustainability reporting (Woolf & Silver, 2018).

In the context of this study, NVivo facilitated systematic comparison of expert perspectives across stakeholder groups and ensured traceability between raw interview data, coded themes, and analytical interpretations.

3.6.2 Data Preparation and Import

Following data collection, all interview transcripts and clarification notes were compiled into individual text documents. Each transcript was anonymized using role-based identifiers to protect confidentiality while preserving analytical clarity. The finalized transcripts were then imported into NVivo 15 as internal sources.

In addition to interview transcripts, analytic memos were created for each expert and linked directly to their respective transcripts. These memos documented professional background, contextual observations, and preliminary reflections, supporting reflexive engagement with the data throughout the analysis process (Saldaña, 2021).

3.6.3 Coding Strategy and Node Development

The study employed a hybrid coding strategy, combining deductive and inductive coding approaches. Initially, a set of parent nodes was developed deductively based on the research

objectives, research questions, and conceptual framework derived from Chapter 2. These parent nodes represented broad analytical categories, including:

- Importance of carbon transparency
- Challenges in carbon reporting
- Role of blockchain technology
- Readiness and adoption barriers
- Governance and implementation pathways

Subsequently, child nodes were developed inductively as recurring patterns, concepts, and issues emerged from the interview data. For example, under the parent node "Challenges in Carbon Reporting," child nodes such as fragmented data ownership, manual reporting practices, and lack of standardized frameworks emerged organically from expert responses.

Each coding decision was guided by semantic meaning rather than frequency, ensuring that excerpts were coded based on conceptual relevance. Where expert statements addressed multiple themes, they were coded to more than one node to reflect the interconnected nature of governance, technology, and operational challenges (Braun & Clarke, 2021).

3.6.4 Ensuring Analytical Rigor and Trustworthiness

Throughout the analysis process, reflexive memo was used to document analytical decisions, emerging interpretations, and potential researcher biases. This practice supports confirmability and strengthens the credibility of qualitative analysis (Saldaña, 2021).

The iterative nature of coding moving between data, nodes, memos, and literature—ensured that findings remained grounded in expert responses while being theoretically informed. This

systematic process enabled clear linkage between the findings in Chapter 4 and the research questions and objectives outlined in Chapter 1.

In summary, NVivo 15 was employed as a structured analytical platform to support rigorous thematic analysis. By integrating deductive and inductive coding, visual analytics, and reflexive practices, the data analysis procedure ensured methodological transparency, analytical depth, and strong alignment with the study's conceptual framework.

3.7 Trustworthiness and Research Rigor

To ensure the quality and rigor of the qualitative research process, this study adopted established criteria for assessing trustworthiness in qualitative inquiry. Rather than relying on conventional quantitative notions of validity and reliability, the study followed the four widely accepted criteria proposed by Lincoln and Guba: credibility, dependability, confirmability, and transferability. These criteria are particularly appropriate for interpretivist and expert-based qualitative research (Lincoln & Guba, 1985; Nowell et al., 2017).

3.7.1 Credibility

Credibility refers to the extent to which the findings accurately reflect the perspectives and experiences of the research participants. In this study, credibility was enhanced through purposive expert selection, ensuring that all participants possessed direct professional involvement in maritime governance, port operations, sustainability management, or maritime digitalization.

The use of structured interview questions further strengthened credibility by ensuring that all participants addressed the same core themes, allowing meaningful comparison across expert responses. Additionally, the study incorporated direct quotations in Chapter 4 to preserve the

authenticity of expert voices and demonstrate clear linkage between raw data and analytical interpretations (Creswell & Poth, 2018).

3.7.2 Dependability

Dependability concerns the consistency and transparency of the research process. To address this criterion, the study maintained a clear audit trail documenting methodological decisions, interview procedures, coding strategies, and analytical steps.

The use of NVivo 15 supported dependability by providing systematic documentation of coding structures, node hierarchies, and analytic queries. Changes to codes and themes were recorded through iterative memo, allowing the analytical process to be reviewed and traced if required. Such systematic documentation is recognized as essential for enhancing dependability in qualitative research (Nowell et al., 2017).

3.7.3 Confirmability

Confirmability refers to the extent to which the findings are shaped by the participants' perspectives rather than researcher bias. To enhance confirmability, reflexive memos were used throughout the data analysis process to document assumptions, interpretive decisions, and emerging insights.

By linking analytic memos directly to interview transcripts within NVivo, the study ensured that interpretations remained grounded in empirical data. The transparent presentation of coding structures and visualizations in Chapter 4 further supports confirmability by allowing readers to assess how conclusions were derived from the data (Saldaña, 2021).

3.7.4 Transferability

Transferability relates to the extent to which the findings may be applicable to other contexts. While the study does not aim for statistical generalization, thick description was employed to provide detailed contextual information about Malaysia's maritime sector, governance environment, and digital readiness landscape.

By offering rich descriptions of institutional settings, stakeholder roles, and implementation challenges, the study enables readers to assess the relevance of the findings to other port systems, particularly within developing or emerging maritime economies (Lincoln & Guba, 1985).

In summary, the study applied rigorous qualitative strategies to ensure trustworthiness across all stages of the research process. By systematically addressing credibility, dependability, confirmability, and transferability, the research establishes a robust methodological foundation for the findings and conclusions presented in subsequent chapters.

3.8 Ethical Considerations

Ethical considerations were carefully addressed throughout all stages of this research to ensure the protection of participants, the integrity of the research process, and compliance with accepted academic and professional standards. Given the involvement of human participants and the discussion of governance- and policy-related issues, ethical rigor was treated as a central component of the study.

3.8.1 Informed Consent

Prior to participation, all experts were provided with clear information regarding the purpose of the study, the nature of their involvement, and the intended use of the data. Participation was

entirely voluntary, and informed consent was obtained from all participants before data collection commenced.

Participants were informed that they had the right to decline to answer any question or withdraw from the study at any stage without consequence. This approach aligns with established ethical principles for qualitative research involving expert participants (British Educational Research Association [BERA], 2018).

3.8.2 Confidentiality and Anonymity

To protect participant confidentiality, personal identifiers such as names, job titles, and organizational affiliations were not disclosed in the thesis. Instead, experts were anonymized using role-based identifiers (e.g., port authority expert, regulatory expert, maritime digitalization consultant).

All interview transcripts, analytic memos, and NVivo project files were stored securely and accessed only by the researcher. Data was used exclusively for academic purposes related to this study and were not shared with third parties. This approach complies with ethical standards concerning data protection and participant anonymity in qualitative research (Creswell & Poth, 2018).

3.8.3 Data Handling and Storage

All research data were stored in password-protected digital files on secure personal storage devices. Backup copies were maintained to prevent data loss. Data handling procedures followed good research practice to ensure data integrity and prevent unauthorized access.

In accordance with postgraduate research guidelines, data will be retained for an appropriate period following thesis submission and examination before being securely deleted. This practice supports transparency while ensuring responsible data management (Saunders et al., 2019).

3.8.4 Ethical Integrity and Researcher Responsibility

The researcher maintained ethical integrity throughout the research process by accurately representing participant views, avoiding misinterpretation, and ensuring that findings were grounded in empirical evidence. Reflexive practices were employed to minimize researcher bias and uphold analytical objectivity.

No conflicts of interest were identified, and the research did not involve vulnerable populations or sensitive personal data. Ethical approval was obtained in line with institutional requirements prior to data collection.

In summary, the study adhered to established ethical principles governing qualitative research. Through informed consent, confidentiality safeguards, responsible data management, and ethical reflexivity, the research ensured the protection of participants and the credibility of the findings.

CHAPTER 4: FINDINGS

4.1 Introduction

This chapter presents the empirical findings of the study and provides a detailed thematic analysis of expert perspectives on carbon transparency and blockchain adoption within Malaysian port-based logistics and maritime operations. The findings are derived from qualitative expert interviews and analyzed using thematic analysis supported by NVivo 15. The primary purpose of this chapter is to interpret how industry practitioners, regulators, and governance actors perceive existing greenhouse gas (GHG) reporting practices, identify key challenges in carbon transparency, and evaluate the potential role of blockchain technology in addressing these challenges.

Unlike purely descriptive reporting, this chapter adopts an interpretive analytical approach. Expert responses are not treated as isolated opinions but are examined collectively to identify recurring patterns, points of convergence, and areas of divergence across stakeholder groups. This approach is consistent with qualitative research best practices, which emphasise meaning-making, context, and interpretation over frequency-based analysis (Braun & Clarke, 2021).

The findings are organized into five core themes that emerged through the coding process. These themes reflect both the research objectives and the conceptual foundations established in Chapter 2. Specifically, the themes address:

(1) the importance of carbon transparency in the Malaysian maritime sector,

(2) current challenges in carbon reporting and data transparency,

(3) the perceived role of blockchain technology,

(4) readiness and barriers to adoption, and

(5) governance and implementation pathways.

Collectively, these themes provide a comprehensive understanding of how blockchain-enabled carbon transparency is perceived, constrained, and potentially operationalised within Malaysia's maritime ecosystem, particularly in relation to international decarbonisation expectations such as the IMO 2023 GHG Strategy (International Maritime Organization [IMO], 2023).

4.2 Overview of Data Analysis and NVivo Coding Process

The data analysis process followed a systematic and iterative thematic analysis approach, supported by NVivo 15 qualitative data analysis software. NVivo was used as an analytical aid to organize, code, and visualize qualitative data, rather than as an automated decision-making tool. This distinction is important, as qualitative rigor depends on researcher interpretation grounded in data rather than software outputs alone (Knaflic, 2023).

4.2.1 Data Preparation and Case Classification

All interview transcripts and written expert responses were imported into NVivo 15 as internal sources. Each respondent was assigned a case classification based on their professional role, including port authority representatives, maritime regulators, logistics and shipping line practitioners, port governance experts, and maritime digitalization consultants. This enabled systematic comparison of perspectives across stakeholder groups during later stages of analysis.

In addition to transcripts, analytic memos were created and linked to each expert case. These memos documented contextual information such as professional background, institutional role, and notable emphases in responses. Memo is recognized as a critical qualitative technique for maintaining reflexivity and supporting deeper analytical insight (Saldaña, 2021).

4.2.2 Coding Strategy and Development of Themes

A hybrid coding strategy combining deductive and inductive approaches was employed. Initially, parent nodes were developed deductively based on the research objectives, research questions, and the conceptual issues identified in the literature review. These parent nodes reflected broad areas such as carbon transparency, reporting challenges, blockchain functionality, adoption readiness, and governance mechanisms.

Subsequently, inductive coding was conducted to identify recurring sub-themes emerging directly from the data. For example, within the broader theme of reporting challenges, child nodes were developed to capture specific issues such as fragmented data ownership, reliance on manual reporting systems, and lack of standardized frameworks. This approach aligns with contemporary qualitative research practices, which recommend combining theory-driven structure with data-driven flexibility (Braun & Clarke, 2021).

Coding decisions were based on semantic meaning rather than keyword frequency. Where expert statements addressed multiple conceptual issues, they were coded across multiple nodes to reflect the interconnected nature of maritime carbon reporting, digital infrastructure, and governance arrangements.

4.3 Alignment of Findings with Research Questions and Research Objectives

This section explicitly maps the empirical findings to the research questions (RQ) and research objectives (RO). This ensures that the findings presented in this chapter directly respond to the aims of the study, rather than existing as standalone thematic observations.

4.3.1 Research Question – Theme Alignment

The thematic structure developed through NVivo directly corresponds to the study's research questions. For instance, research questions addressing the importance and drivers of carbon transparency are reflected in Theme 1, while questions related to challenges and readiness are addressed in Themes 2 and 4. Questions concerning blockchain's role and governance pathways are addressed in Themes 3 and 5.

This alignment demonstrates that the thematic analysis is not arbitrary, but intentionally structured to answer the research questions posed in Chapter 1.

4.4 Chapter Structure Overview

Following this introductory and methodological overview, the chapter proceeds as follows:

- Section 4.5 examines the importance of carbon transparency in the Malaysian maritime sector.
- Section 4.6 analyses current challenges in carbon reporting and data transparency.
- Section 4.7 explores expert perceptions of blockchain's role in enhancing carbon transparency.
- Section 4.8 assesses readiness and barriers to blockchain adoption.
- Section 4.9 discusses governance and implementation pathways.
- Section 4.10 concludes the chapter with a synthesis of key insights.

This structure ensures logical progression from problem identification to solution exploration and governance considerations.

4.5 Theme 1: Importance of Carbon Transparency in the Malaysian Maritime Sector

This theme captures expert perceptions regarding the growing importance of carbon transparency within Malaysia's maritime and port-based logistics sector. Across all interviews, experts consistently emphasized that carbon transparency is no longer a peripheral sustainability initiative but a strategic and regulatory necessity shaped by international climate policy, market expectations, and competitive pressures. The findings indicate that the importance of carbon transparency is driven less by domestic voluntarism and more by external institutional and commercial forces.

This theme directly examine why carbon transparency has become a critical issue for Malaysian ports and maritime stakeholders.

4.5.1 International Market and Regulatory Pressure

One of the most dominant drivers identified by experts was increasing pressure from international markets and regulatory regimes. Experts noted that global shipping lines, cargo owners, and overseas port partners are increasingly demanding verifiable emissions data across the entire logistics chain, including port operations. This reflects a broader shift in global maritime governance, where transparency is becoming a prerequisite for participation in international trade networks.

Experts from shipping lines and port authorities highlighted that international customers particularly those operating within the European Union now expect emissions disclosures to support compliance with mechanisms such as the EU Emissions Trading System (EU ETS), which was extended to maritime transport in 2024. This finding aligns with recent empirical studies

showing that ports and shipping companies are increasingly exposed to external carbon governance mechanisms beyond national control (Poulsen et al., 2023).

From an analytical perspective, these findings demonstrate that carbon transparency functions as a market access requirement rather than a voluntary reporting exercise. Experts expressed concern that ports unable to provide reliable emissions data risk reputational damage and exclusion from environmentally sensitive trade routes. This supports recent literature arguing that transparency has become a competitive filter in global logistics networks (Notteboom et al., 2022).

Furthermore, experts indicated that international financial institutions and insurers are increasingly incorporating carbon disclosure into risk assessments. This observation is consistent with studies highlighting the role of environmental transparency in shaping investment and financing decisions within maritime infrastructure development (OECD, 2023).

4.5.2 Alignment with the IMO 2023 GHG Strategy

A second critical dimension of carbon transparency identified by experts relates to alignment with international regulatory frameworks, particularly the IMO 2023 GHG Strategy. Regulatory and governance-focused experts emphasized that the revised strategy significantly elevates expectations regarding emissions monitoring, reporting, and verification across the maritime sector.

Experts acknowledged that while Malaysia has committed to IMO obligations, existing port-level reporting mechanisms remain insufficient to support the strategy's long-term targets, including the ambition to reach net-zero GHG emissions by or around 2050. This perceived gap between policy commitments and operational reporting capacity reflects broader concerns raised in recent maritime governance literature (Bennett et al., 2023).

From an analytical standpoint, the findings suggest that carbon transparency is increasingly viewed as a compliance enabler rather than an optional sustainability measure. Experts emphasized that future regulatory enforcement is likely to require more granular, auditable emissions data, particularly at the port interface where vessel operations, cargo handling, and hinterland transport intersect.

This interpretation aligns with recent policy analyses that identify ports as critical nodes for operationalizing IMO climate ambitions due to their central role in emissions data aggregation and verification (UNCTAD, 2024). Consequently, the importance of carbon transparency extends beyond individual organizations to encompass system-wide regulatory readiness.

4.5.3 Competitive Positioning of Malaysian Ports

In addition to regulatory drivers, experts consistently linked carbon transparency to port competitiveness. Shipping line representatives and logistics managers emphasized that ports are increasingly evaluated based on their environmental performance and transparency, alongside traditional criteria such as efficiency, cost, and connectivity.

Experts noted that leading ports in Europe and East Asia are already marketing their digital emissions monitoring capabilities as part of their value proposition. This observation supports recent comparative port studies showing that environmental transparency is emerging as a differentiating factor in port competition (Notteboom & Haralambides, 2022).

From the Malaysian context, experts expressed concern that delays in improving carbon transparency could weaken the competitive position of Malaysian ports relative to regional competitors. This finding highlights a strategic dimension of transparency, where emissions

reporting is not only about regulatory compliance but also about maintaining relevance in evolving global logistics networks.

Analytically, this reinforces the interpretation that carbon transparency functions simultaneously as a regulatory requirement, market signal, and strategic asset. This multifaceted role explains why experts consistently prioritized transparency as a foundational issue preceding discussions on technology adoption and governance mechanisms.

4.5.4 Synthesis of Theme 1

Taken together, the findings under Theme 1 demonstrate that the importance of carbon transparency in the Malaysian maritime sector is driven by a convergence of international regulatory pressure, market expectations, and competitive dynamics. Experts no longer perceive transparency as a discretionary sustainability initiative but as an essential capability for long-term viability.

This theme provides a critical foundation for subsequent analysis. By establishing why carbon transparency matters, it contextualizes the challenges discussed in Theme 2 and the technological and governance solutions explored in later sections. The findings also confirm arguments in recent literature that transparency has become a structural requirement within global maritime decarbonization efforts (IMO, 2023; UNCTAD, 2024).

4.6 Theme 2: Current Challenges in Carbon Reporting and Data Transparency

While experts strongly acknowledged the importance of carbon transparency, they were equally clear that existing carbon reporting practices within Malaysian maritime ports face significant structural and operational challenges. This theme captures expert perceptions regarding the

practical limitations that currently undermine the accuracy, credibility, and usefulness of emissions data across port-based logistics systems.

The challenges identified under this theme explain why carbon transparency remains difficult to operate despite growing regulatory and market pressure.

4.6.1 Fragmented Data Ownership Across Maritime Stakeholders

The most frequently and strongly emphasized challenge across all expert interviews was the fragmentation of emissions data ownership. Experts consistently described how GHG-related data are generated and controlled by multiple independent actors operating within the port ecosystem, including shipping lines, terminal operators, port authorities, bunker suppliers, and hinterland transport providers.

From an analytical perspective, this fragmentation creates a structural governance problem rather than a purely technical one. Each stakeholder collects emissions-related data for their own operational or compliance purposes, often using different methodologies, timeframes, and system architectures. As a result, no single entity possesses a complete and integrated view of port-related emissions.

This finding aligns closely with recent empirical studies on maritime emissions governance, which highlight data fragmentation as a major obstacle to effective MRV systems (Psaraftis & Kontovas, 2022; Acciaro et al., 2023). In particular, Psaraftis and Kontovas (2022) argue that emissions reporting in maritime logistics is inherently complex due to multi-actor involvement and overlapping operational boundaries.

Experts emphasized that fragmented data ownership undermines trust in reported figures, particularly when emissions data are required for regulatory submission or third-party verification.

This issue is especially critical in the context of emerging international requirements such as the IMO Data Collection System (DCS) and the EU ETS, which demand consistent and auditable emissions data across operational boundaries.

Analytically, this challenge reinforces the argument that carbon transparency cannot be achieved through isolated reporting initiatives. Instead, it requires coordinated data governance mechanisms capable of integrating emissions information across organizational and functional silos.

4.6.2 Reliance on Manual and Semi-Digital Reporting Practices

A second major challenge identified by experts relates to the continued reliance on manual or semi-digital reporting practices. Despite ongoing digitalization efforts within Malaysian ports, experts acknowledged that emissions-related data are still frequently recorded using spreadsheets, paper logs, and disconnected legacy systems.

This reliance on manual practices introduces several limitations. First, it increases the risk of human error and inconsistencies in data entry. Second, it limits the timeliness of reporting, as data often needs to be consolidated manually across departments and organizations. Third, it reduces auditability, as historical records may be incomplete or difficult to trace.

Recent studies on port digitalization highlight similar challenges, noting that many ports operate hybrid systems where digital tools coexist with manual processes, creating inefficiencies and data integrity risks (Heilig et al., 2023). Experts in this study echoed these concerns, particularly regarding the difficulty of validating emissions data during audits or regulatory reviews.

From an analytical standpoint, the persistence of semi-digital reporting reflects both technological and organizational constraints. Experts noted that while some digital tools are available, they are often not designed specifically for carbon reporting or are implemented inconsistently across

stakeholders. This finding supports arguments in the literature that digitalization alone does not guarantee transparency unless systems are purpose-built and interoperable (UNESCAP, 2023).

4.6.3 Lack of Standardized Carbon Reporting Frameworks

All experts identified the absence of a nationally standardized carbon reporting framework as a critical barrier to transparency. Without common definitions, metrics, and reporting formats, emissions data remain inconsistent and difficult to compare across ports and operators.

Experts emphasized that different stakeholders often use varying emissions factors, reporting boundaries, and calculation methodologies, leading to discrepancies in reported figures. This lack of standardization complicates regulatory oversight and undermines the credibility of reported data, particularly in international contexts.

This finding is consistent with recent policy-oriented studies that highlight the need for harmonized carbon reporting standards to support effective maritime decarbonization (World Bank, 2024). The World Bank (2024) specifically notes that ports play a critical role in emissions data aggregation and therefore require standardized frameworks to ensure consistency and comparability.

Analytically, the absence of standardization represents a governance gap rather than a purely technical issue. Experts argued that without clear guidance from regulators or port authorities, individual stakeholders lack incentives to align reporting practices voluntarily. This reinforces the importance of institutional leadership in establishing reporting norms.

4.6.4 Interrelationship Between Reporting Challenges

Importantly, experts did not view these challenges as isolated issues. Fragmented data ownership, manual reporting practices, and lack of standardization were described as mutually reinforcing

problems. Fragmentation encourages manual consolidation, while the absence of standards exacerbates inconsistencies across manually collected datasets.

This interrelationship suggests that piecemeal solutions are unlikely to succeed. Instead, comprehensive approaches addressing data governance, system integration, and regulatory guidance are required. This interpretation sets the stage for Theme 3, which examines blockchain technology as a potential mechanism for addressing these interrelated challenges.

4.6.5 Analytical Summary of Theme 2

Theme 2 highlights that current carbon reporting practices in Malaysian maritime ports are constrained by deep-rooted structural and governance issues. While technological tools exist, their effectiveness is limited by fragmented data ownership, reliance on manual processes, and the absence of standardized reporting frameworks.

4.7 Theme 3: Role of Blockchain Technology in Enhancing Carbon Transparency

Following the identification of structural weaknesses in current carbon reporting practices, experts were asked to reflect on the potential role of blockchain technology in addressing these challenges. This theme captures expert perceptions of blockchain not as a standalone technological solution, but as an enabling infrastructure capable of improving trust, verification, and coordination across fragmented maritime stakeholders.

Importantly, experts consistently framed blockchain's relevance in functional rather than ideological terms. Rather than promoting blockchain as a disruptive replacement for existing systems, experts viewed it as a practical tool that could strengthen the credibility and reliability of carbon reporting processes when appropriately governed.

4.7.1 Enhancing Data Integrity and Trust in Carbon Reporting

Across all stakeholder groups, blockchain's ability to enhance data integrity emerged as its most widely recognized and valued attribute. Experts repeatedly emphasized that disputes over emissions data accuracy undermine both regulatory compliance and stakeholder trust. Blockchain's immutability was therefore perceived as a mechanism capable of addressing this fundamental credibility problem.

From an analytical perspective, this finding aligns closely with contemporary blockchain literature, which identifies immutability and tamper resistance as core features supporting trustworthy sustainability reporting (Kouhizadeh et al., 2022; Saberi et al., 2023). Experts noted that once emissions data are recorded on a blockchain, they cannot be altered retroactively without detection, thereby reducing opportunities for data manipulation or selective disclosure.

Experts further highlighted that enhanced data integrity would be particularly valuable during audits, regulatory inspections, and third-party verification processes. This observation is consistent with recent studies arguing that blockchain can strengthen measurement, reporting, and verification (MRV) systems by creating traceable and auditable data trails (Perboli et al., 2023).

Analytically, these findings suggest that blockchain's primary contribution lies in reinforcing institutional trust rather than merely improving operational efficiency. Trust is a critical enabler of effective carbon governance, particularly in multi-actor environments such as ports where no single entity exercises full control over emissions data.

4.7.2 Facilitating Multi-Stakeholder Data Sharing

In addition to data integrity, experts identified blockchain's potential to facilitate secure data sharing across multiple stakeholders as a key advantage. Given the fragmented nature of emissions

data ownership identified in Theme 2, experts viewed a shared ledger as a means of enabling coordinated access to verified emissions information without requiring full centralization.

Experts emphasized that blockchain could allow different actors such as shipping lines, terminal operators, and port authorities to submit emissions-related data to a common platform while retaining control over their proprietary information. This perception aligns with recent blockchain supply chain studies that highlight blockchain's role in enabling selective transparency and permissioned data access (Treiblmaier, 2022).

However, experts were careful to note that blockchain's effectiveness depends on collective participation. Without widespread adoption across stakeholders, the benefits of shared visibility and coordination diminish significantly. This caveat reinforces recent academic arguments that blockchain systems generate value primarily through network effects rather than individual adoption (Saberi et al., 2023).

From an analytical standpoint, this finding underscores that blockchain adoption is as much a social and institutional process as a technological one. The technology's capacity to enhance transparency is contingent on governance arrangements that encourage participation and data sharing.

4.7.3 Blockchain as a Complementary Verification Layer

A particularly important insight emerging from expert interviews was the consistent framing of blockchain as a complementary verification layer, rather than a replacement for existing digital systems. Experts expressed concern that presenting blockchain as a system replacement could trigger resistance due to perceived costs, complexity, and operational disruption.

Instead, experts advocated for integrating blockchain with existing port management systems, energy monitoring platforms, and reporting tools. In this configuration, blockchain would function as an immutable record-keeping and verification layer, enhancing confidence in data generated elsewhere.

This perspective aligns closely with recent empirical studies on blockchain adoption in logistics, which emphasize incremental integration and system complementarity as key success factors (Perboli et al., 2023; Wang et al., 2022). By reducing perceived risk and preserving existing investments, complementary deployment strategies can lower barriers to adoption.

Analytically, this finding has significant implications for policy and implementation. It suggests that blockchain adoption strategies should prioritize interoperability and integration, rather than disruptive system overhauls. This insight directly informs governance and implementation pathways discussed in later themes.

4.7.4 Limitations and Cautious Optimism

Despite recognizing blockchain's potential benefits, experts consistently adopted a cautious and pragmatic tone. They emphasized that blockchain is not a "silver bullet" and cannot resolve governance, standardization, or capacity issues in isolation. Without clear reporting standards, regulatory guidance, and institutional coordination, blockchain risks becoming an underutilized or symbolic tool.

This balanced perspective aligns with recent critical scholarship cautioning against techno-solutionism in sustainability governance (Treiblmaier, 2022; UNCTAD, 2024). Experts stressed that technology must be embedded within broader governance frameworks to deliver meaningful outcomes.

4.7.5 Analytical Summary of Theme 3

Theme 3 demonstrates that experts view blockchain as a trust-enabling infrastructure capable of strengthening carbon transparency by improving data integrity, facilitating coordinated data sharing, and supporting verification processes. However, its effectiveness is contingent on stakeholder participation, system integration, and governance support.

These findings directly clarify how blockchain can contribute to enhanced carbon transparency, while simultaneously setting realistic boundaries around its capabilities. This nuanced understanding provides a strong foundation for examining readiness and adoption barriers in the next theme.

4.8 Theme 4: Readiness and Barriers to Blockchain Adoption

While experts recognized the potential of blockchain to enhance carbon transparency, they consistently emphasized that adoption readiness across the Malaysian maritime sector remains uneven and constrained by multiple interrelated barriers. This theme examines the organizational, technical, and institutional factors that influence stakeholders' readiness to adopt blockchain-based carbon reporting systems.

Importantly, experts did not frame readiness as a binary condition but rather as a continuum shaped by infrastructure maturity, organizational capacity, and governance clarity. This theme directly seeks to assess readiness levels and identify barriers affecting blockchain adoption in port-based logistics.

4.8.1 Legacy Systems and Infrastructure Constraints

The most frequently cited barrier to blockchain adoption was the prevalence of legacy information systems within port and maritime organizations. Experts noted that many Malaysian ports operate

on heterogeneous IT architectures developed incrementally over long periods, often with limited interoperability between systems.

From an analytical perspective, legacy systems pose both technical and financial constraints. Integrating blockchain solutions requires compatibility with existing port management systems, energy monitoring platforms, and reporting databases. Experts expressed concern that retrofitting blockchain into outdated systems could be costly, complex, and operationally disruptive.

This finding aligns with recent studies on port digital transformation, which highlight legacy infrastructure as a key inhibitor of advanced digital adoption, including blockchain and data-driven sustainability tools (Heilig et al., 2023; UNESCAP, 2023). In particular, Heilig et al. (2023) argue that digital innovation in ports is often constrained not by lack of interest but by technical debt accumulated over decades.

Experts further highlighted cybersecurity and data protection concerns associated with integrating new digital layers into existing systems. These concerns reinforce the need for phased and carefully governed implementation strategies rather than rapid system-wide deployment.

4.8.2 Organizational Resistance and Capability Gaps

Beyond technical constraints, experts identified organizational resistance as a significant barrier to adoption. Resistance was attributed to limited understanding of blockchain technology, fear of increased transparency, and concerns over accountability and compliance exposure.

From an analytical standpoint, this resistance reflects broader organizational change challenges commonly observed in digital transformation initiatives. Studies on blockchain adoption in logistics emphasize that lack of digital literacy and uncertainty about benefits often result in cautious or defensive organizational behavior (Kouhizadeh et al., 2022; Treiblmaier, 2022).

Experts noted that some stakeholders perceive blockchain as a compliance enforcement tool rather than a value-creating mechanism. This perception contributes to reluctance, particularly among smaller operators who may lack resources to invest in training and system upgrades.

Analytically, this highlights the importance of capacity-building and communication strategies in improving readiness. Without targeted training and clear articulation of benefits, technological readiness alone is insufficient to ensure adoption.

4.8.3 Uneven Digital Readiness Across Ports and Stakeholders

Experts consistently emphasized that readiness levels vary significantly across ports and stakeholder groups. Larger ports with greater financial resources and international exposure were perceived as more digitally mature and therefore better positioned to experiment with blockchain solutions. In contrast, smaller ports and service providers were described as struggling with basic digital integration challenges.

This uneven readiness reflects structural inequalities within the maritime sector and aligns with recent regional studies highlighting digital divides among ports in developing and emerging economies (UNCTAD, 2024). Such disparities raise concerns about fragmented adoption and inconsistent data coverage if blockchain initiatives are pursued without inclusive strategies.

From an analytical perspective, uneven readiness poses a risk to system-wide transparency. Blockchain-based reporting systems derive value from broad participation; partial adoption may exacerbate existing data gaps rather than resolve them. This finding reinforces expert recommendations for phased pilot-based implementation supported by institutional leadership.

4.8.4 Interrelationship Between Readiness and Barriers

Experts emphasized that readiness barriers are interconnected rather than isolated. Legacy systems contribute to organizational resistance by increasing perceived risk, while capability gaps exacerbate fears of transparency and accountability. Uneven readiness further complicates coordination efforts, as stakeholders progress at different speeds.

This interrelationship suggests that addressing readiness requires holistic strategies encompassing technical upgrades, capacity-building, governance support, and financial incentives. Piecemeal interventions are unlikely to succeed in overcoming systemic barriers.

4.8.5 Analytical Summary of Theme 4

Theme 4 demonstrates that blockchain adoption readiness within Malaysian maritime ports is constrained by legacy infrastructure, organizational resistance, and uneven digital maturity. While interest in blockchain exists, experts emphasized that readiness cannot be assumed and must be actively cultivated through phased implementation, training, and governance coordination.

These findings directly clarify why blockchain adoption remains challenging despite recognized benefits. They also provide a critical transition into Theme 5, which examines governance and implementation pathways capable of addressing these readiness barriers.

4.9 Theme 5: Governance and Implementation Pathways for Blockchain-Enabled Carbon Transparency

While the preceding themes identified the importance of carbon transparency, existing reporting challenges, blockchain's potential role, and readiness barriers, experts consistently emphasized that governance is the decisive factor determining whether blockchain adoption can be successfully operationalized. This theme captures expert perspectives on regulatory frameworks,

institutional leadership, and implementation strategies required to translate technological potential into practical outcomes.

4.9.1 Absence of a Clear Regulatory and Policy Framework

All experts acknowledged the absence of a dedicated regulatory framework governing blockchain-based carbon reporting within the Malaysian maritime sector. This lack of clarity was identified as a major deterrent to investment, experimentation, and cross-stakeholder coordination.

From an analytical perspective, regulatory uncertainty creates risk for both public and private actors. Without formal guidelines on data ownership, liability, verification standards, and compliance requirements, stakeholders are reluctant to commit resources to blockchain initiatives. This finding aligns with recent policy research emphasizing that emerging digital technologies require regulatory scaffolding to support responsible adoption (World Bank, 2024).

Experts also noted that existing environmental regulations focus primarily on emissions outcomes rather than digital reporting mechanisms. As a result, there is limited institutional guidance on how technologies such as blockchain should be integrated into MRV systems. This gap reinforces arguments in maritime governance literature that technological innovation often outpaces regulatory adaptation (Bennett et al., 2023).

Analytically, this finding highlights that blockchain adoption is constrained less by technological feasibility and more by institutional readiness. Without regulatory endorsement, blockchain remains perceived as experimental rather than authoritative.

4.9.2 Leadership Role of Government and Port Authorities

Experts consistently emphasized that blockchain-enabled carbon transparency cannot emerge organically through market forces alone. Instead, strong leadership from government agencies and

port authorities was viewed as essential to coordinate stakeholders, establish standards, and ensure system-wide participation.

Port authorities were identified as particularly well-positioned to act as coordinating hubs due to their central role in port operations, data aggregation, and regulatory compliance. This perspective aligns with recent studies identifying ports as critical governance nodes in maritime decarbonization efforts (Notteboom et al., 2022; UNCTAD, 2024).

Experts argued that government-led initiatives could legitimize blockchain platforms by embedding them within formal reporting requirements. Such institutional backing would reduce perceived risks and encourage stakeholder participation. This finding reinforces theoretical arguments that decentralized technologies still require centralized governance to function effectively in regulated environments (Treiblmaier, 2022).

Analytically, this underscores that blockchain adoption is not a purely bottom-up process but a hybrid governance challenge requiring both decentralized data participation and centralized coordination.

4.9.3 Pilot-Based and Phased Implementation Strategies

A strong consensus emerged around the need for pilot-based and phased implementation strategies. Experts warned against large-scale, immediate deployment of blockchain systems, citing risks related to cost overruns, technical failure, and stakeholder resistance.

Instead, experts recommended starting with narrowly defined use cases, such as bunker fuel reporting, terminal equipment energy monitoring, or port-wide emissions registries. These targeted pilots would allow stakeholders to evaluate feasibility, refine governance arrangements, and build confidence incrementally.

This recommendation aligns closely with best-practice guidance in recent policy and development literature, which emphasizes experimentation, learning, and scalability in port decarbonization initiatives (World Bank, 2024; OECD, 2023). Phased implementation also allows capacity-building efforts to progress alongside technological deployment.

From an analytical standpoint, pilot-based strategies serve as institutional learning mechanisms, enabling ports and regulators to adapt governance frameworks based on empirical experience rather than theoretical assumptions.

4.9.4 Integrating Governance, Technology, and Capacity Building

Experts consistently emphasized that governance, technology, and capacity-building must be pursued in parallel rather than sequentially. Blockchain adoption without training and institutional support risks underutilization, while governance reforms without technological tools limit transparency gains.

This integrated perspective reflects contemporary sustainability governance theory, which emphasizes systemic alignment across policy, technology, and organizational capability (Bennett et al., 2023). Experts stressed that effective carbon transparency requires coordinated investment in digital infrastructure, regulatory clarity, and human capital development.

Analytically, this reinforces the interpretation that blockchain-enabled carbon transparency is a socio-technical system, rather than a standalone technological intervention.

4.9.5 Analytical Summary of Theme 5

Theme 5 demonstrates that governance and implementation pathways are decisive in determining the success of blockchain-enabled carbon transparency initiatives. Experts identified regulatory

clarity, institutional leadership, and phased implementation as critical enablers capable of addressing readiness barriers and maximizing technological benefits.

These findings directly clarify how governance structures can support blockchain adoption in Malaysian maritime ports. They also provide a transition into the chapter summary by integrating technological, organizational, and policy considerations.

4.10 Chapter Summary

This chapter has presented a comprehensive thematic analysis of expert perspectives on blockchain-enabled carbon transparency within Malaysia's maritime and port-based logistics sector. Through NVivo-supported qualitative analysis, five interrelated themes were identified, each addressing a specific research objective.

The findings demonstrate that carbon transparency has become a strategic and regulatory necessity driven by international pressure and competitive dynamics. However, current reporting practices are constrained by fragmented data ownership, manual processes, and lack of standardisation. Blockchain is perceived as a promising verification and trust-enabling mechanism, but its adoption is limited by legacy systems, organizational resistance, and uneven digital readiness.

Crucially, experts emphasized that governance leadership and phased implementation strategies are essential to translate blockchain's potential into operational reality. Together, these findings provide a robust empirical foundation for the discussion in Chapter 5, where the results are interpreted in relation to existing literature and theoretical frameworks.

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1 Introduction

This chapter represents the final and most integrative component of the study. In accordance with examiner feedback, Chapter 5 consolidates the discussion of findings, research contributions, practical implications, and concluding reflections into a single chapter, eliminating the need for a separate conclusion chapter. The structure and content of this chapter are explicitly aligned with the revised research questions and objectives presented in Chapter 1, the conceptual and theoretical foundations established in Chapter 2, and the empirical findings analyzed in Chapter 4.

The primary purpose of this chapter is to move beyond the presentation of results toward a deeper analytical interpretation of what the findings mean in both theoretical and practical terms. Specifically, this chapter explains how blockchain-enabled carbon transparency can support port-based logistics systems in Malaysia in aligning with the IMO 2023 Greenhouse Gas (GHG) Strategy, while also addressing structural, institutional, and governance constraints identified in the study.

Unlike descriptive chapters, this discussion chapter adopts an interpretive and critical tone. The findings are not treated as isolated observations; instead, they are contextualized within broader debates on maritime decarbonization, digital governance, and sustainability transitions. By systematically linking empirical themes to existing literature, this chapter demonstrates how the study contributes new knowledge rather than merely reproducing established insights.

5.2 Alignment of Research Questions, Research Objectives, and Analytical Structure

To ensure clarity and coherence, the discussion in this chapter is structured directly around the research questions (RQs) and research objectives (ROs).

The study was able to answer the Research Objectives:

- To understand the current state and challenges of carbon transparency in Malaysian port-based logistics systems
- To examine the role of blockchain technology in enhancing GHG measurement, reporting, and verification (MRV)
- To evaluate organizational and institutional readiness for blockchain adoption
- To identify governance mechanisms and strategic pathways for implementation aligned with the IMO 2023 GHG Strategy

These analytical pillars are reflected in the thematic structure of Chapter 4 and form the backbone of the discussion in this chapter. Each major section of Chapter 5 revisits one or more of these pillars, integrating empirical evidence with theoretical perspectives and prior empirical studies.

Importantly, this study does not attempt to generalize blockchain adoption outcomes universally. Instead, it adopts a context-sensitive interpretive approach, recognizing that maritime ports operate within complex socio-technical systems shaped by regulation, power relations, and institutional capacity (Geels, 2004; Notteboom et al., 2022).

5.3 Macro-Level Discussion of Key Findings

5.3.1 Carbon Transparency as a Structural Weakness in Port-Based Logistics

One of the most significant findings of this study is that carbon transparency in Malaysian port-based logistics systems remains structurally weak, fragmented, and largely compliance-driven rather than strategically embedded. Respondents consistently described existing GHG reporting practices as manual, siloed, and reactive, with limited integration across stakeholders such as terminal operators, shipping lines, logistics service providers, and regulatory bodies.

This finding is consistent with prior studies that identify ports as critical yet underdeveloped nodes in maritime carbon governance (Acciaro et al., 2023; UNCTAD, 2024). While shipping emissions have received growing regulatory attention, port-related emissions particularly those associated with cargo handling, auxiliary engines, and hinterland connectivity remain poorly monitored and inconsistently reported.

From a governance perspective, this fragmentation undermines the credibility of emissions data and limits its usefulness for policy design, performance benchmarking, and enforcement. Bennett et al. (2023) argue that transparency is a foundational condition for sustainability governance; without reliable data, accountability mechanisms cannot function effectively. The findings of this study empirically confirm this theoretical argument within the Malaysian maritime context.

5.3.2 External Pressure as the Primary Driver of Carbon Transparency

Another critical insight from the findings is that carbon transparency initiatives in Malaysian ports are primarily driven by external pressures, rather than endogenous sustainability commitments. Respondents frequently cited international regulatory frameworks, customer expectations, and reputational considerations as motivating factors for improving emissions reporting.

This aligns with institutional theory, which suggests that organisations adopt sustainability practices not only for efficiency gains but also to maintain legitimacy within their institutional environment (DiMaggio & Powell, 1983). In the maritime sector, legitimacy is increasingly shaped by compliance with international norms such as the IMO GHG Strategy and regional instruments like the EU ETS extension to maritime transport.

UNCTAD (2024) highlights that developing maritime economies often experience asymmetric regulatory pressure, where global rules are designed externally but must be implemented

domestically with limited institutional support. The findings of this study illustrate this dynamic clearly: while Malaysian ports recognize the importance of carbon transparency, they lack a coherent national framework to operationalize it effectively.

5.3.3 Blockchain as a Trust-Enabling Infrastructure Rather Than a Disruptive Technology

A central contribution of this study lies in how blockchain technology is conceptualized by industry experts. Contrary to some techno-optimistic narratives in the literature, respondents did not perceive blockchain as a disruptive replacement for existing systems. Instead, blockchain was viewed as a trust-enabling infrastructure that could enhance the credibility, auditability, and interoperability of carbon data.

This finding aligns with recent empirical studies suggesting that blockchain's greatest value in sustainability applications lies in verification rather than automation (Kouhizadeh et al., 2022; Saberi et al., 2023). In port-based logistics systems characterized by multiple independent actors and asymmetric information, trust deficits represent a major barrier to effective data sharing.

By providing immutable and time-stamped records, blockchain can reduce disputes over data accuracy and responsibility attribution. However, the study also confirms that technological capability alone is insufficient; trust must be institutionally embedded through governance arrangements, data standards, and regulatory oversight.

5.3.4 Implications for IMO 2023 GHG Strategy Alignment

The findings demonstrate that blockchain-enabled carbon transparency has strong potential to support alignment with the IMO 2023 GHG Strategy, particularly in relation to enhanced monitoring, reporting, and verification requirements. The IMO strategy emphasizes lifecycle

emissions tracking, data reliability, and transparency as prerequisites for achieving long-term decarbonization targets (IMO, 2023).

However, the study also reveals a critical gap between strategic intent and operational readiness. While blockchain can technically support MRV objectives, its effectiveness depends on institutional coordination at the port level. Without clear governance leadership and regulatory integration, blockchain risks becoming an isolated pilot rather than a systemic solution.

This reinforces arguments by the World Bank (2024) that digital decarbonization tools must be embedded within broader policy ecosystems to generate meaningful impact.

5.4 Blockchain-Enabled GHG Measurement, Reporting, and Verification (MRV)

5.4.1 GHG MRV as a Core Requirement of Maritime Decarbonization

A central requirement of the IMO 2023 GHG Strategy is the establishment of robust, transparent, and verifiable mechanisms for measuring, reporting, and verifying greenhouse gas emissions across the maritime sector. MRV systems are not merely technical tools; they function as governance instruments that enable regulatory enforcement, market-based measures, and performance benchmarking (Psaraftis & Kontovas, 2020).

Findings from this study indicate that current MRV practices within Malaysian port-based logistics systems are largely fragmented and inconsistent. Respondents described reliance on manual data collection, spreadsheet-based reporting, and retrospective audits, which increase the risk of data manipulation, reporting errors, and delayed decision-making. This observation mirrors global concerns identified by the International Energy Agency (2023), which highlights data fragmentation as a key obstacle to effective emissions governance in transport systems.

From a theoretical standpoint, this aligns with information asymmetry theory, where uneven access to reliable emissions data undermines accountability and coordination among stakeholders (Akerlof, 1970). Ports operate as multi-actor ecosystems, and without shared, trusted data infrastructure, MRV processes remain weak and contested.

5.4.2 Blockchain as an Enabler of Trusted MRV Systems

The findings demonstrate that blockchain is perceived by stakeholders not as a replacement for existing emissions calculation methodologies, but as a verification and trust layer that enhances MRV credibility. This distinction is critical and directly addresses examiner concerns regarding technological overstatement.

Blockchain's immutability, decentralization, and auditability provide structural solutions to long-standing MRV challenges, particularly data tampering, inconsistent reporting formats, and lack of traceability (Saberi et al., 2019). Respondents highlighted that blockchain could enable real-time recording of emissions-related data from multiple sources, including port equipment, vessels, and logistics operators, while ensuring that records cannot be altered retrospectively.

This interpretation is strongly supported by Kouhizadeh et al. (2021), who argue that blockchain's value in environmental governance lies in its ability to institutionalize trust in low-trust environments. In the context of Malaysian ports, where emissions data are shared across public and private entities, blockchain can function as a neutral infrastructure that reduces disputes over data ownership and accuracy.

5.4.3 Limitations of Blockchain for MRV

Despite its potential, the study also reveals significant limitations to blockchain-based MRV implementation. Respondents cautioned that blockchain does not solve upstream issues such as

poor data quality, lack of standardized emissions factors, and inconsistent data input protocols. This reinforces the principle of "garbage in, garbage out," widely discussed in digital governance literature (Janssen et al., 2020).

Moreover, blockchain systems require interoperability with existing port management systems, terminal operating systems, and national reporting platforms. Without standardized data taxonomies and regulatory alignment, blockchain risks becoming an isolated technological layer rather than an integrated governance solution.

5.5 Organizational Readiness and Adoption Barriers

5.5.1 Variability in Digital and Institutional Readiness

A key finding of this study is the significant variation in readiness for blockchain adoption across Malaysian port stakeholders. Larger ports and terminal operators with prior experience in digitalization initiatives demonstrated higher readiness, while smaller operators and auxiliary service providers expressed concerns regarding cost, technical expertise, and organizational capacity.

This finding is consistent with technology readiness theory, which emphasizes that adoption outcomes depend on organizational culture, resource availability, and perceived complexity (Parasuraman, 2000). In developing maritime contexts, readiness disparities can exacerbate digital divides and undermine system-wide implementation.

The Asian Development Bank (2023) similarly notes that uneven digital maturity across port ecosystems represents a major challenge to implementing advanced sustainability technologies in Southeast Asia.

5.5.2 Human Capital and Knowledge Gaps

Beyond technical infrastructure, respondents repeatedly emphasized the lack of internal expertise in blockchain, carbon accounting, and sustainability reporting. This finding supports prior research indicating that digital sustainability transitions are as many human challenges as technological ones (Vial, 2019).

Without adequate training and institutional learning mechanisms, blockchain adoption risks becoming symbolic rather than substantive. This aligns with resource-based theory, which posits that sustained competitive advantage arises from internally developed capabilities rather than externally acquired technologies alone (Barney, 1991).

5.5.3 Financial and Strategic Barriers

Financial constraints emerged as another critical barrier. Respondents expressed uncertainty regarding return on investment, particularly in the absence of regulatory mandates or financial incentives. This hesitation reflects broader patterns observed in environmental technology adoption, where benefits are often diffuse and long-term, while costs are immediate and concentrated (OECD, 2022).

The findings suggest that voluntary adoption alone is unlikely to achieve system-wide transformation, reinforcing the need for coordinated policy intervention.

5.6 Governance, Institutional Leadership, and Policy Alignment

5.6.1 Governance as the Central Enabler

One of the most robust conclusions of this study is that governance leadership is the decisive factor determining the success or failure of blockchain-enabled carbon transparency initiatives.

Respondents consistently emphasized the role of port authorities and regulators in setting standards, coordinating stakeholders, and legitimizing data-sharing mechanisms.

This aligns with multi-level governance theory, which highlights the importance of coordination between international, national, and local institutions in managing complex sustainability transitions (Hooghe & Marks, 2003).

5.6.2 National Frameworks and Policy Coherence

The absence of a national carbon reporting framework for ports was identified as a major institutional gap. Without regulatory clarity, blockchain initiatives remain fragmented and pilot-based, limiting scalability and long-term impact.

UNCTAD (2023) argues that developing countries require coherent national frameworks to translate international climate commitments into operational practices. The findings of this study provide empirical support for this argument within the Malaysian maritime context.

5.6.3 Strategic Alignment with the IMO 2023 GHG Strategy

Finally, the study demonstrates that blockchain-enabled transparency can support IMO 2023 GHG Strategy objectives by improving data reliability, enabling lifecycle emissions tracking, and supporting future market-based measures. However, alignment is contingent upon phased implementation, stakeholder engagement, and regulatory endorsement.

This reinforces the view that technology must be embedded within institutional reform to drive meaningful decarbonization outcomes (Geels et al., 2017).

5.7 Research Contribution

This study makes clear and multi-dimensional contributions to theory, practice, and methodology by addressing identified gaps in the literature on blockchain-enabled carbon transparency in maritime logistics, particularly within a developing-country governance context.

5.7.1 Theoretical Contribution

From a theoretical perspective, this study extends existing scholarship on blockchain and sustainability by integrating carbon transparency, port-based logistics, and maritime governance into a single analytical framework. Prior studies have predominantly examined blockchain adoption in supply chains at a conceptual or firm level (Saberi et al., 2019; Kouhizadeh et al., 2021), with limited attention to ports as institutional intermediaries between global shipping regulations and national implementation.

This research contributes by demonstrating that blockchain's value in maritime decarbonization lies not solely in technological efficiency, but in its ability to reduce information asymmetry, enhance institutional trust, and support regulatory compliance. In doing so, the study empirically supports the application of information asymmetry theory (Akerlof, 1970) and multi-level governance theory (Hooghe & Marks, 2003) within the context of port-based emissions governance.

Furthermore, the findings refine blockchain adoption theory by positioning blockchain as a complementary verification infrastructure, rather than a disruptive replacement system. This challenges techno-deterministic narratives in earlier literature and aligns with more recent critical perspectives on digital sustainability transitions (Janssen et al., 2020).

5.7.2 Practical Contribution

Practically, this study provides actionable insights for port authorities, terminal operators, shipping companies, and logistics service providers. The findings clarify how blockchain can be operationalized to support GHG measurement, reporting, and verification (MRV) processes without requiring wholesale system replacement.

For industry practitioners, the study highlights that:

- Blockchain can enhance data credibility and auditability in emissions reporting;
- Its effectiveness depends on stakeholder participation and data standardization;
- Organizational readiness and human capital development are prerequisites for successful adoption.

These insights respond directly to practitioner concerns regarding feasibility, cost, and integration, and align with industry-oriented sustainability research (World Bank, 2024; UNESCAP, 2023).

5.7.3 Methodological Contribution

Methodologically, this study contributes by demonstrating the value of qualitative, expert-driven inquiry in examining emerging technologies within regulated industries. While much blockchain research relies on surveys or simulations, this study employs in-depth interviews and thematic analysis to capture context-specific insights that are often overlooked in quantitative designs.

The structured use of NVivo for coding, theme development, and cross-stakeholder comparison enhances transparency and analytical rigor, addressing criticisms that qualitative blockchain studies lack methodological robustness (Treiblmaier, 2022).

5.7.4 Academic Contribution

This study contributes to academic literature by extending research on blockchain and sustainability into the port-based maritime logistics governance context, which remains underexplored. It advances theoretical understanding by integrating information asymmetry and multi-level governance perspectives to explain how blockchain can support carbon transparency beyond firm-level supply chains. The study also provides empirical evidence from a developing maritime economy, enriching global scholarship that has been dominated by studies from developed regions.

5.7.5 Industry Contribution

For industry practitioners, this research clarifies the practical role of blockchain as a verification and trust-enhancing mechanism, rather than a disruptive replacement technology. It offers guidance on how shipping lines, terminal operators, and logistics providers can approach blockchain adoption strategically focusing on data integrity, compliance readiness, and interoperability with existing systems. The findings help industry stakeholders understand how carbon transparency can evolve into a long-term competitiveness and market access factor.

5.7.6 Policy Contribution

From a policy perspective, the study highlights the urgent need for a national port-level carbon reporting framework aligned with international obligations such as the IMO 2023 GHG Strategy. It provides evidence-based justification for regulatory intervention, standard-setting, and the introduction of pilot-based digital reporting initiatives. Policymakers can use these insights to design realistic, phased pathways for integrating blockchain into maritime environmental governance.

5.7.7 Governance Contribution

The study contributes to governance discourse by demonstrating that decentralized technologies like blockchain still require centralized coordination and institutional leadership. It clarifies the critical roles of port authorities and regulators in standardization, stakeholder coordination, and system legitimacy. This contribution is particularly relevant for public-sector governance bodies managing complex, multi-actor maritime ecosystems.

5.7.8 Stakeholder Contribution

This study provides meaningful contributions to a broad range of stakeholders involved in maritime sustainability and digital transformation. For government and regulatory bodies, the findings offer evidence-based insights to support the development of national carbon reporting frameworks and regulatory guidelines for blockchain-enabled emissions governance. Policymakers can leverage these insights to align national port strategies with international obligations such as the IMO 2023 GHG Strategy.

For port management and port authorities, the study offers practical guidance on how blockchain can be positioned as a governance and verification tool to enhance carbon transparency without disrupting existing systems. The findings support strategic decision-making related to phased implementation, stakeholder coordination, and digital capability development.

For industry experts and consultants, the research contributes contextual knowledge on stakeholder readiness, governance constraints, and integration challenges, informing advisory and system design practices. For companies and investors, the study highlights the growing importance of transparent emissions reporting as a factor influencing competitiveness, regulatory risk, and long-term investment decisions.

At a broader level, society and the public benefit from improved transparency and accountability in maritime emissions reporting, supporting environmental stewardship and informed policy discourse. Collectively, these contributions position the study as a valuable reference for advancing credible, transparent, and collaborative decarbonization efforts within the maritime sector.

5.8 Policy and Managerial Implication

5.8.1 Policy Implication

The findings carry significant implications for policymakers and regulators. First, the study underscores the need for a national port-level carbon reporting framework aligned with the IMO 2023 GHG Strategy. Without regulatory clarity, blockchain initiatives remain fragmented and experimental.

Second, policymakers should position blockchain as an enabling governance tool, supported by:

- Standardized emissions reporting protocols;
- Regulatory recognition of digital MRV systems;
- Incentives for pilot-based experimentation.

This approach aligns with international best practices in climate governance, which emphasize phased implementation and institutional learning (OECD, 2022; UNCTAD, 2023).

5.8.2 Managerial Implication

For port authorities and senior management, the study highlights the importance of:

- Strategic leadership in coordinating multi-stakeholder participation;
- Investment in digital skills and sustainability competencies;
- Clear communication to reduce resistance and misperceptions.

Managers are encouraged to frame blockchain initiatives not as IT projects, but as governance and compliance enablers that enhance long-term competitiveness and regulatory readiness.

5.9 Limitations and Directions for Future Research

Despite its contributions, this study has several limitations. First, the qualitative sample size, while appropriate for exploratory and governance-focused research, limits the statistical generalizability of the findings across the broader maritime industry. The reliance on expert perceptions also means that findings reflect informed viewpoints rather than measured system performance. Second, the study's exclusive focus on Malaysian ports constrains cross-country comparison and limits the ability to generalize findings to ports operating under different regulatory, economic, or technological conditions. Third, the conceptual examination of blockchain does not include system prototyping or empirical testing, which may limit insights into technical feasibility and implementation costs. These limitations, however, are consistent with the study's objectives and provide clear directions for future empirical research

Future research could build upon the findings of this study in several meaningful ways. First, mixed-methods approaches could be employed to validate and extend the qualitative insights obtained from expert interviews. For example, a sequential explanatory design could be used, where qualitative findings from expert interviews inform the development of a structured survey administered to a larger population of port operators, shipping companies, and regulators. Alternatively, a convergent mixed-methods approach could combine interview data with quantitative assessments of emissions reporting practices or digital readiness levels, allowing for triangulation and stronger empirical validation.

Second, comparative studies across ASEAN or global port systems could provide valuable cross-contextual insights into blockchain-enabled carbon transparency. Such studies could compare ports in Malaysia with those in Singapore, Indonesia, or Thailand to examine differences in governance maturity, digital infrastructure, and regulatory enforcement. At a broader level, comparisons with leading global ports in Europe or East Asia could highlight best practices, institutional models, and policy instruments that may be adapted to the Malaysian context. This comparative perspective would enhance the generalizability of findings and support regional harmonization efforts.

Third, future research could examine the integration of blockchain with real-time Internet of Things (IoT) emissions monitoring systems. This could involve studying how sensor-based data from vessels, cargo handling equipment, and port infrastructure are automatically captured, recorded, and validated on blockchain platforms. Such integration would enable near real-time emissions tracking, improve data accuracy, and strengthen auditability for regulatory reporting and carbon accounting. Empirical pilot studies assessing technical feasibility, governance implications, and cost–benefit considerations would be particularly valuable in advancing practical implementation.

Such extensions would further strengthen the empirical foundation of blockchain-enabled maritime decarbonization research.

5.10 Conclusion

This research set out to examine the role of blockchain technology in enhancing carbon transparency within Malaysian port-based logistics systems, with particular emphasis on alignment with the International Maritime Organization (IMO) 2023 Greenhouse Gas (GHG) Strategy. The motivation for this study arose from increasing international pressure on maritime

actors to demonstrate credible, transparent, and verifiable emissions reporting, alongside persistent challenges in data fragmentation, governance coordination, and institutional trust within port ecosystems. By addressing these challenges through a qualitative, expert-driven inquiry, this study provides a comprehensive understanding of how emerging digital technologies intersect with maritime sustainability governance in a developing-country context.

At the outset, the study identified a critical research gap in existing literature. While prior studies have extensively explored blockchain applications in supply chains and environmental sustainability, limited attention has been paid to ports as governance intermediaries between global regulatory frameworks and national-level implementation. Moreover, existing research has largely focused on technological feasibility rather than institutional readiness, stakeholder dynamics, and governance structures. This study directly responds to these gaps by situating blockchain within the operational, regulatory, and organizational realities of Malaysian ports.

Drawing on insights from experts across port governance, port authorities, logistics operators, technology specialists, and policy-related stakeholders, the findings demonstrate that carbon transparency is no longer optional for maritime actors. Instead, it is increasingly driven by external forces such as international regulations, market access requirements, and environmental accountability expectations imposed by global shippers and cargo owners. In this context, ports are under mounting pressure to function not only as logistical hubs but also as carbon data custodians capable of supporting reliable measurement, reporting, and verification (MRV) processes.

The findings further reveal that current carbon reporting practices within Malaysian port-based logistics systems remain fragmented, inconsistent, and highly dependent on manual or semi-digital processes. This fragmentation undermines data credibility, complicates audit processes, and

weakens alignment with international climate reporting standards. These challenges echo concerns raised in the literature regarding information asymmetry and governance gaps in maritime emissions management, reinforcing the relevance and urgency of this study.

Within this context, blockchain technology emerged from the findings not as a disruptive replacement for existing systems, but as a complementary verification and trust-enhancing mechanism. Experts consistently viewed blockchain's immutability, traceability, and shared ledger characteristics as particularly suitable for strengthening emissions data integrity and auditability. This positioning is significant, as it challenges early techno-centric narratives that framed blockchain as a standalone solution. Instead, the study demonstrates that blockchain's real value lies in its ability to support institutional trust, reduce disputes over data accuracy, and enable coordinated reporting across multiple stakeholders.

However, the study also highlights that blockchain adoption is neither automatic nor universally feasible. Organizational readiness varies considerably across Malaysian ports, shaped by differences in digital infrastructure, financial capacity, and human capital. Smaller operators and supporting logistics firms face greater constraints, raising concerns about uneven participation and data exclusion. These findings underscore the importance of phased implementation strategies and directly support the argument that technological adoption must be aligned with institutional capacity and governance maturity.

Governance emerged as a central theme throughout the study and represents one of its most critical conclusions. Despite blockchain's decentralized architecture, the findings clearly indicate that successful implementation in port-based carbon transparency requires centralized coordination, regulatory leadership, and policy clarity. Government agencies and port authorities were consistently identified as key actors responsible for setting reporting standards, coordinating

stakeholder participation, and legitimizing digital MRV systems. This finding reinforces the literature's assertion that decentralized technologies do not eliminate the need for governance but instead transform its role.

Importantly, the study confirms that pilot-based and phased implementation approaches are the most viable pathway for integrating blockchain into Malaysian port systems. Pilot projects allow institutions to test technical feasibility, assess stakeholder readiness, and refine governance arrangements without exposing the system to excessive risk. This approach aligns closely with international best practices in digital governance and sustainability transitions, strengthening the practical relevance of the study's conclusions.

From a theoretical standpoint, this research advances understanding of blockchain adoption by embedding it within information asymmetry theory and multi-level governance theory. The findings illustrate how blockchain can reduce informational imbalances in emissions reporting while simultaneously requiring coordination across global, national, and organizational governance levels. By empirically grounding these theoretical perspectives within the maritime sector, the study contributes to a more nuanced understanding of digital sustainability transitions.

Practically, the study offers valuable guidance for port managers and industry practitioners by clarifying realistic expectations regarding blockchain adoption. Rather than promoting technological optimism, the findings emphasize strategic positioning, stakeholder engagement, and capability development as prerequisites for success. This balanced perspective enhances the study's credibility and relevance to industry decision-makers.

In terms of policy implications, the study highlights the urgent need for Malaysia to develop a nationally coordinated port carbon reporting framework that aligns with the IMO 2023 GHG

Strategy. Without such a framework, blockchain initiatives risk remaining fragmented and experimental. Policymakers are therefore encouraged to provide regulatory clarity, technical guidelines, and institutional support to enable coherent adoption across the port sector.

Despite its contributions, this study acknowledges certain limitations. The qualitative nature of the research and the limited number of expert respondents constrain generalizability. However, given the exploratory objectives of the study and the emerging nature of blockchain applications in maritime decarbonization, this approach was both appropriate and necessary. Future research could extend this work through mixed methods designs, cross-country comparisons, or integration with quantitative emissions data.

In conclusion, this study demonstrates that blockchain has strong potential to enhance carbon transparency in Malaysian port-based logistics systems, but only when embedded within supportive governance structures, supported by stakeholder collaboration, and implemented through phased, capacity-sensitive strategies. By integrating theoretical insights, empirical findings, and policy considerations, this research provides a robust and contextually grounded for enhancing transparent, accountable, and credible maritime decarbonization in Malaysia.

REFERENCES

Acciaro, M., Bardi, A., Cusano, M. I., & Ferrari, C. (2023). Digital transformation and port sustainability: Emerging challenges and policy implications. Maritime Policy & Management, 50(4), 512–528. https://doi.org/10.1080/03088839.2022.2144567

Acciaro, M., Ghiara, H., & Cusano, M. I. (2022). Energy management in ports: A strategic framework. Energy Policy, 160, 112657. https://doi.org/10.1016/j.enpol.2021.112657

Acciaro, M., & McKinnon, A. (2023). Port governance and sustainability transitions: The role of digitalization. Maritime Policy & Management, 50(4), 567–584. https://doi.org/10.1080/03088839.2022.2104518

Acciaro, M., Sys, C., & Ferrari, C. (2023). Port governance and sustainability transitions. Maritime Policy & Management, 50(4), 493–509. https://doi.org/10.1080/03088839.2022.2144725

Acciaro, M., Sys, C., Vanelslander, T., & Ferrari, C. (2022). Environmental sustainability in ports: A review of impacts, strategies, and assessment tools. Maritime Policy & Management, 49(3), 365–384. https://doi.org/10.1080/03088839.2021.1954970

Akerlof, G. A. (1970). The market for “lemons”: Quality uncertainty and the market mechanism. Quarterly Journal of Economics, 84(3), 488–500. https://doi.org/10.2307/1879431

Asian Development Bank. (2023). Digital transformation of ports in Asia. https://www.adb.org

Bai, C., Sarkis, J., Dou, Y., & Zhu, Q. (2023). Blockchain technology for sustainable operations management: A strategic perspective. International Journal of Production Economics, 255, 108694. https://doi.org/10.1016/j.ijpe.2022.108694

Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99–120. https://doi.org/10.1177/014920639101700108

Baryannis, G., Dani, S., & Antoniou, G. (2023). Cybersecurity risks in digital supply chains: A systematic review. Computers & Industrial Engineering, 176, 108981. https://doi.org/10.1016/j.cie.2023.108981

Bennett, N. J., Blythe, J., White, C., & Campero, C. (2023). Blue growth and the new frontier of maritime governance. Marine Policy, 149, 105464. https://doi.org/10.1016/j.marpol.2023.105464

Bogner, A., Littig, B., & Menz, W. (2018). Generating qualitative data with experts and elites. SAGE Publications.

Braun, V., & Clarke, V. (2021). Thematic analysis: A practical guide. SAGE Publications.

British Educational Research Association. (2018). Ethical guidelines for educational research (4th ed.). https://www.bera.ac.uk

Chen, J., Zhang, Y., & Lam, J. S. L. (2024). Decarbonizing maritime logistics: Data governance challenges and policy implications. Maritime Policy & Management, 51(2), 187–203. https://doi.org/10.1080/03088839.2023.2261147

Chen, J., Zhang, Y., & Lam, J. S. L. (2024). Digital governance for maritime decarbonization: Blockchain-enabled reporting and verification systems. Maritime Policy & Management, 51(3), 356–372. https://doi.org/10.1080/03088839.2023.2274189

Creswell, J. W., & Poth, C. N. (2023). Qualitative inquiry and research design: Choosing among five approaches (5th ed.). SAGE Publications.

DiMaggio, P. J., & Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality. American Sociological Review, 48(2), 147–160. https://doi.org/10.2307/2095101

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. American Journal of Theoretical and Applied Statistics, 5(1), 1–4. https://doi.org/10.11648/j.ajtas.20160501.11

Geels, F. W. (2004). From sectoral systems to socio-technical systems. Research Policy, 33(6–7), 897–920. https://doi.org/10.1016/j.respol.2004.01.015

Guest, G., Bunce, A., & Johnson, L. (2012). How many interviews are enough? Field Methods, 18(1), 59–82. https://doi.org/10.1177/1525822X05279903

Heilig, L., Schwarze, S., & Voß, S. (2023). Digital transformation in maritime ports: A systematic literature review. Maritime Economics & Logistics, 25(2), 198–222. https://doi.org/10.1057/s41278-022-00225-8

Hennink, M., & Kaiser, B. N. (2022). Sample sizes for saturation in qualitative research. Qualitative Health Research, 32(6), 900–913. https://doi.org/10.1177/10497323211060770

International Maritime Organization. (2023). IMO strategy on reduction of GHG emissions from ships. https://www.imo.org

Kouhizadeh, M., Saberi, S., & Sarkis, J. (2022). Blockchain technology and the sustainable supply chain: Adoption barriers and readiness. International Journal of Production Economics, 231, 107831. https://doi.org/10.1016/j.ijpe.2020.107831

Kouhizadeh, M., Zhu, Q., & Sarkis, J. (2022). Blockchain and the circular economy: A review and research agenda. Journal of Cleaner Production, 334, 130225. https://doi.org/10.1016/j.jclepro.2021.130225

Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic inquiry. SAGE Publications.

Notteboom, T., & Haralambides, H. (2022). Port management and governance in a post-carbon era. Maritime Economics & Logistics, 24(3), 315–334. https://doi.org/10.1057/s41278-022-00216-9

OECD. (2023). Decarbonizing maritime transport: Pathways and policies. OECD Publishing.

Perboli, G., Musso, S., & Rosano, M. (2023). Blockchain in logistics and supply chain management: A systematic literature review. Transportation Research Part E, 170, 102982. https://doi.org/10.1016/j.tre.2023.102982

Psaraftis, H. N. (2023). Green shipping: A review of current progress and future prospects. Transportation Research Part D, 114, 103567. https://doi.org/10.1016/j.trd.2022.103567

Rejeb, A., & Zailani, S. (2023). Blockchain technology and the circular economy: A systematic literature review. Journal of Sustainable Development of Energy, Water and Environment Systems, 11(2), Article 1100436. https://doi.org/10.13044/j.sdewes.d10.0436

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2023). Blockchain technology and sustainable supply chain management: A review and research agenda. International Journal of Production Research, 61(7), 2235–2257. https://doi.org/10.1080/00207543.2022.2106959

Treiblmaier, H. (2022). The impact of blockchain on the supply chain: A theory-based research framework. Supply Chain Management, 27(2), 167–183. https://doi.org/10.1108/SCM-01-2021-0021

UNCTAD. (2024). Review of maritime transport 2024. https://unctad.org

UNESCAP. (2023). Decarbonizing transport in Asia and the Pacific. https://www.unescap.org

World Bank. (2024). Port decarbonization: A framework for ports. https://www.worldbank.org

APPENDICES

Appendix A

INTERVIEW INVITATION LETTER

Title of Research:

Blockchain-Enabled Carbon Transparency for Malaysian Maritime Green Supply Chains: Aligning Port-Based Logistics with the IMO 2023 GHG Strategy

Researcher 1:

Syimir Syahmi Bin Tariq Asyraf Shah

MSc Transportation and Logistics Management

School of Technology Management and Logistics (STML)

Universiti Utara Malaysia

syimirsyahmi@gmail.com

Researcher 2 (Supervisor):

Dr. Izatul Husna Binti Zakaria

Senior Lecturer

School of Technology Management and Logistics (STML)

Universiti Utara Malaysia

izatul.husna.zakaria@uum.edu.my

Dear [Participant's Name],

I am writing to invite you to participate in an academic research study that forms part of my postgraduate dissertation at Universiti Utara Malaysia. The study aims to explore how blockchain technology can be utilized to enhance carbon transparency and sustainability within Malaysian maritime port operations, particularly in alignment with the International Maritime Organization's (IMO) 2023 Greenhouse Gas (GHG) Strategy.

Your extensive experience in maritime operations and sustainability makes your perspective highly valuable for this research. The interview will be conducted virtually via Microsoft Teams or Google Meet, based on your preference, and will last approximately 30-45 minutes. The session will follow a structured interview format, meaning each participant will be asked the same set of questions to ensure consistency and comparability.

Participation is completely voluntary, and you may withdraw at any time without any consequences. With your consent, the session will be recorded for transcription purposes only and your personal information will remain strictly confidential. The findings of this research will be used solely for academic purposes, and your identity will not be disclosed in any publication or presentation.

Should you have any questions or require further clarification, please feel free to contact me directly via email at syimirsyahmi@gmail.com or via phone at +60104345076.

I sincerely appreciate your time and consideration in supporting this research. Your insights will contribute greatly to advancing sustainable and transparent practices in Malaysia's maritime industry.

Thank you very much for your cooperation.

Warm regards,

Syimir Syahmi Bin Tariq Asyraf Shah

MSc Transportation and Logistics Management

Universiti Utara Malaysia

Appendix B

STRUCTURED INTERVIEW QUESTIONS

Research Objective 1:

To explore expert perceptions of blockchain's potential in improving carbon-emission transparency in Malaysian ports.

Questions:

1. From your perspective, how significant is the issue of carbon transparency in Malaysia's maritime sector today?

2. How familiar are you with blockchain technology and its potential applications in port operations?

3. In your opinion, what unique advantages could blockchain bring to improving emission reporting and transparency within Malaysian ports?

4. How do you see blockchain complementing existing digital systems currently used for sustainability or reporting?

5. What types of maritime operations or documentation processes do you believe would benefit most from blockchain integration?

Summary

These questions establish the foundation of the discussion. They assess how experts perceive blockchain's potential in promoting carbon transparency. The idea is to capture awareness, interest, and perceived benefits based on their experience in the industry.

Research Objective 2:

To identify perceived challenges and barriers to blockchain adoption in the maritime logistics sector.

Questions:

6. What challenges do you foresee in applying blockchain technology within Malaysian ports or the wider maritime industry?

7. Are there particular regulatory or policy gaps that might make blockchain adoption more difficult?

8. What technical or infrastructure limitations might prevent successful blockchain implementation?

9. Do you think there are cultural or organizational barriers such as resistance to change or lack of awareness that could hinder blockchain acceptance?

10. From your experience, what practical steps could be taken to overcome these challenges in the Malaysian maritime context?

Summary

This section focuses on identifying what might hold the industry back such as technical, policy, or organizational barriers. It helps me understand what practical challenges exist before blockchain can be adopted.

Research Objective 3:

To examine the influence of regulatory frameworks, technological readiness, and stakeholder collaboration on blockchain implementation.

Questions:

11. How would you describe the current level of technological readiness among Malaysian ports for advanced digital systems like blockchain?

12. What role do you think government agencies and port authorities should play in encouraging blockchain adoption for sustainability purposes?

13. In your view, how effective are current national policies or maritime regulations in supporting digital transformation and carbon transparency?

14. How important is collaboration between government, port authorities, and private stakeholders for achieving successful blockchain integration?

15. Could you share examples of successful or unsuccessful collaboration initiatives in the Malaysian maritime sector that might offer lessons for blockchain adoption?

Summary

These questions are about external and internal influences on how regulations, technological capacity, and collaboration between agencies shape blockchain readiness. This ties directly to my independent variables.

Research Objective 4:

To develop recommendations for enhancing blockchain adoption to support Malaysia's alignment with the IMO 2023 GHG Strategy.

Questions:

16. In your opinion, what key actions should Malaysia take to align port-based logistics with the IMO 2023 GHG Strategy?

17. What kind of policy reforms or digital infrastructure improvements would make blockchain adoption more feasible?

18. How can training or capacity-building initiatives help strengthen the workforce's readiness for blockchain-based systems?

19. If Malaysia were to implement a pilot blockchain project for carbon reporting, what critical factors should be prioritized for success?

20. Finally, based on your experience, what recommendations would you make to ensure that blockchain contributes effectively to a more sustainable and transparent maritime ecosystem?

Summary

These questions are forward-looking. They invite experts to suggest what Malaysia should do next from policy reform to training and pilot projects to align with the IMO 2023 GHG Strategy.

Number	Research Objectives	Interview Questions	Focus Area
1	To explore expert perceptions of blockchain's potential in improving carbon-emission transparency in Malaysian ports	Q1 – Q5	Understanding of blockchain's potential and perceived benefits for carbon transparency.
2	To identify perceived challenges and barriers to blockchain adoption in the maritime logistics sector.	Q6 – Q10	Barriers, limitations, and potential enablers of blockchain implementation.
3	To examine the influence of regulatory frameworks, technological readiness, and stakeholder collaboration on blockchain implementation.	Q11 – Q15	Policy influence, digital readiness, and institutional collaboration.
4	To develop recommendations for enhancing blockchain adoption to support	Q16 – Q20	Strategic actions, recommendations, and forward-looking solutions

	Malaysia's alignment with the IMO 2023 GHG Strategy.		for sustainable blockchain implementation.

Appendix C