SUSTAINABLE BUNKER USE IN MARITIME: ASSESSING THE STRATEGIC SHIFT TOWARDS LOW-CARBON ALTERNATIVE FUELS

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ABSTRACT

This research examines the maritime industry's strategic transition towards sustainable fuel supply and alternative fuels, focusing particularly on the gap between international regulatory targets and operational realities. Although the International Maritime Organization (IMO) has set carbon emission reduction targets for 2030 and 2050, the practical implementation of these targets remains largely uncertain. Through 14 in-depth interviews with various industry professionals, including chief engineers, technical managers, fuel suppliers, academics, and interns, this study reveals the multifaceted barriers hindering a smooth “green transition.”

The findings reveal a significant “reality gap” within the sector. Based on data collected from participants, the average readiness score is a low 4.43 out of 10. Three key obstacles emerge as critical “deal-breakers”: financial constraints, infrastructure deficiencies, and the marginalization of the human element. Financially, the “Green Premium” and high capital requirements for fleet renewal pose an existential crisis for medium-sized companies. Logistically, global port infrastructure received a critically low readiness score of 1.28 out of 5, pointing to a “logistical paralysis” for refueling next-generation ships.

Additionally, this study highlights a deep disconnect regarding the workforce. There is 100% consensus among participants that seafarers' views are systematically ignored in strategic decision-making processes. This “top-down” approach, combined with “curriculum lag” in maritime education and increasing administrative burdens, is leading to a loss of motivation among the younger generation of maritime professionals. Consequently, this research reveals that for a successful transition, the industry must move beyond technical and capital-focused models and adopt a more inclusive, people-centered, and infrastructure-focused approach.

Keywords: Sustainable Bunkering, Maritime Decarbonization, Alternative Marine Fuels, IMO Regulations

INTRODUCTION

The Role of Maritime Transport in Global Trade

In the globalizing world economy, logistics is considered the lifeblood of trade. Undoubtedly, the most critical link in this vast network is maritime transport. Today, approximately 80% of world trade by volume and more than 70% by value is carried out by sea (UNCTAD, 2023). From raw materials to automobiles, from energy sources such as LNG and natural gas to complex project cargoes, the continuity of the global supply chain is largely dependent on these ocean-going vessels. Maritime trade plays an indispensable role in the sustainability of the global economy because it is the lowest-cost and highest-capacity mode of transport per unit compared to other modes of transport (air or road).

The Dynamics of Marine Fuels (Bunker) and Operational Efficiency

The operational success of a merchant marine fleet is directly dependent on the energy source that enables ships to reach ports safely and on time, namely the “Bunker” (ship fuel) sector. However, bunker management is not merely a fuel supply process; it is also a complex discipline involving engineering and cost management.

• **Fuel Diversity and Regulations:** Today, ships use different types of fuel depending on their engine types and areas of operation, such as Marine Gas Oil (MGO), Marine Diesel Oil (MDO), Very Low Sulphur Fuel Oil (VLSFO), Ultra Low Sulphur Fuel Oil (ULSFO), and High Sulphur Fuel Oil (HSFO) with high sulphur content.

• **Efficiency and Ship Condition:** A ship's fuel consumption is closely linked to its age, the technological equipment of the main engines and boilers in the engine room, and regular maintenance processes. An older ship with traditional technology can achieve much higher fuel consumption values compared to a modern “eco-design” (newly built) ship.

• **Speed and Cost Relationship:** In shipping, “speed” has an exponential relationship with fuel consumption. Exceeding a certain speed limit dramatically increases fuel consumption, raising operating costs and increasing the environmental footprint. This situation leads to uncontrollable costs, especially in engine rooms where regular maintenance is not performed.

Global Governance and IMO's Role in Sustainable Maritime

The maritime industry is currently navigating through one of its most significant transformations, primarily driven by international regulations aimed at mitigating climate change. The **International Maritime Organization (IMO)** serves as the central governing body, setting the global standards for safety, security, and environmental performance **(IMO, 2023)**. The primary regulatory catalyst is the **MARPOL Annex VI**, which has been progressively tightened to reduce air pollution from ships. The introduction of the **"Global Sulphur Cap"** in 2020, which limited the sulphur content in marine fuels to 0.50%, marked a turning point in bunker management **(Smith et al., 2021)**. Furthermore, the **Initial IMO Strategy on Reduction of GHG Emissions** from ships aims for a total transition to net-zero emissions by or around 2050 **(Psaraftis, 2019)**. These regulations are not merely environmental mandates; they are powerful market drivers that force shipowners to choose between retrofitting existing engines with scrubbers or transitioning to low-carbon alternative fuels like LNG, methanol, or ammonia **(DNV, 2023)**.

Why Sustainable Bunkering Matters Now?

The move toward sustainable bunkering isn't just a trend; it’s driven by two main things: the planet's health and the industry's economic survival. For a long time, traditional heavy fuel oils (HFOs) have been a major source of global pollution, releasing high levels of CO2, SOx, and NOx into the atmosphere

(Eyring et al., 2010). But the days of "business as usual" are fading fast. With new "Green Deal" policies and carbon taxes like the EU Emissions Trading System (EU ETS) starting to include shipping, companies are finding that sticking to old methods is becoming way too expensive **(Stopford, 2022)**.

In today's world, strategic fuel management has changed. It's no longer just about hunting for the lowest bunker price on the market. Instead, it's about ensuring a fleet can remain in business by complying with strict environmental regulations. There is a real danger for ships that can't or won't adapt; they risk becoming what the industry calls "stranded assets." These are essentially vessels that lose their value because they can't keep up with carbon taxes or legal bans **(Christodoulou & Cullinane, 2019)**. Because of this, examining the shift to low-carbon fuels closely is absolutely vital for any fleet that wants to remain competitive in a world that is rapidly decarbonizing.

This research project sought answers to these four questions based on four different research topics. At the end of the research, answers to these four research questions will be found. Within the framework of the findings in the literature and the defined problem, this study focuses on the following technical research questions:

• **RQ1 (Operational/Human Factor):** What are the perceptions of ship personnel (chief engineers and officers) regarding the operational reliability and safety risks (toxicity, flash point, etc.) of new generation fuel systems?

• **RQ2 (Competence):** How critical is the level of expertise of industry stakeholders and ship crews regarding technical regulations such as CII (Carbon Intensity Indicator) and EEXI to the success of compliance strategies?

• **RQ3 (Infrastructure & Logistics):** How does the alternative fuel bunkering infrastructure at ports affect the workload and safety risks of ship personnel during fuel operations?

•**RQ4 (Barriers):** To what extent is the lack of technical competence among current ship personnel to manage alternative fuel technologies a decisive barrier to shipowners' decision to switch to these fuels?

1. LITERATURE REVIEW

Rationale and Motivation

The primary objective of this study is to go beyond academic research and build a bridge based on the field experiences of professionals in the maritime sector. To bridge the gap between theoretical reports and practice, this project is structured around the following three strategic pillars:

1.1. Forced Transition: The Crisis and Opportunity Paradox

Maritime trade is undergoing one of the most radical transformation processes in its history. The 2030 and 2050 decarbonization targets set by the International Maritime Organization (IMO) are forcing the sector to make billion-dollar investments. This situation creates a market leadership "opportunity" for global trade giants with strong financial power, while posing an existential "crisis" for the rest of the sector. The imperative nature of the transformation places strategic marketing and operational alignment capabilities at the heart of the project.

1.2. Decision-Making Uncertainty and Economic Constraints

Global uncertainties are directly impacting sustainability investments. Low freight rates, geopolitical tensions, and war zones along critical trade routes are restricting cash flow. Short-term commercial

operations aimed at "saving the day" dominate the market, while new-building investments have become financially impossible for most companies.

- **The Old Fleet Dilemma:** Due to high interest rates and difficulties in accessing credit, the global fleet is aging, with ships well above IMO standards still actively trading.
- **The Bunker Gamble**: The fact that alternative fuels (methanol, ammonia, etc.) are not yet standardized like the electric vehicle market and remain costly causes companies to view this transition as a risky "gamble." This uncertainty is the biggest psychological and economic barrier to the widespread adoption of sustainable fuels in the market.
- **Human Capital and Regulatory Competence:** The maritime sector has a limited pool of specialized human resources compared to the complexity of regulations. Keeping up with new emissions regulations (CII, EEXI) and changes in bunker trading is not only a matter of technical knowledge but also a strategic competitive advantage. This project aims to measure the adaptation of the limited sectoral workforce to these regulations and the applicability of research in the field.

1.3. Contextual Framework: Reports, Literature, and the Research Gap

1.3.1.Analysis of Global Reports and Sectoral Trends

The pressure on sustainable maritime trade and the bunker sector has been clearly documented in international reports. According to UNCTAD's (2023) "Review of Maritime Transport" report, the maritime sector, which accounts for over 80% of global trade, is responsible for approximately 3% of global greenhouse gas emissions. The decarbonization strategy published by the IMO (2023) mandates a net-zero emissions target by 2050, anticipating the withdrawal of traditional fuels (VLSFO/HSFO) from the market.

However, DNV's (2024) energy transition reports emphasize that this transition will cost trillions of dollars and pose a major operational obstacle for "mid-sized" companies with limited financial resources. Industry reports indicate that alternative fuels (methanol, ammonia, LNG) are not yet as widely available in global bunker ports as electric vehicle charging stations are.

1.3.2.Review of Existing Literature

In academic literature, bunker management is generally examined along two axes:

1. Technical and Engineering Studies: These studies focus on the engine efficiency and chemical emission values of alternative fuels.

2. Legal and Regulatory Studies: Studies addressing the legal framework and sanctions of IMO regulations (such as CII and EEXI).

However, the concept of "sustainability" in the literature is generally discussed from the perspective of large-scale, high-capital companies. The financial constraints of small and medium-sized enterprises (SMEs), aging fleet management, and the uncertainty of the "fuel gamble" in the market have not received the attention they deserve in the literature.

Identifying the Research Gap The fundamental "gap" addressed by this project is as follows: While existing literature and reports generally depict the 'ideal' (a carbon-free future), they do not sufficiently analyze how "real-world" obstacles, such as low freight rates, high credit interest rates, and geopolitical instability, slow down this transformation.

• **The Gap Between Theory and Practice:** Although reports offer technical solutions, there is a lack of qualitative data on how professionals in the field view these fuels in terms of "applicability" and "cost-benefit" balance.

• **Behavioral and Strategic Shortcomings:** There is a limited number of studies examining the strategic dilemma between shipowners' "day-to-day survival" needs and "future investment" using marketing research methodology.

1.4. Problem Definition

Selected SDG Goal: SDG 12 - Responsible Consumption and Production

Focus Area: Strategic barriers and price sensitivity in sustainable bunker fuel adoption among shipowners.

Problem Definition Overview

The maritime sector is undergoing a transition to environmentally friendly fuels due to the IMO's current carbon emission regulations. However, this transition is progressing slower than expected due to low freight rates in the field, high costs, and the time required to adapt to these fuels. Low demand is only a visible symptom; the real problem lies in the underlying financial uncertainty and risk perception. BIMCO (The Baltic and International Maritime Council), one of the sector's largest umbrella organizations, emphasizes that this transition is not only an environmental challenge but also an operational one. According to BIMCO reports, the uncertain environment, dubbed the "Bunker Gamble," is causing ship owners to hesitate about which fuel type (Methanol, Ammonia, or Hydrogen) to invest in. This situation demonstrates the sectoral seriousness of the "strategic wait" and "barriers" that form the basis of our project.

1.4.1. Management Decision Problem (MDP)

Should companies start investing in high-cost and uncertain sustainable bunker fuel now, or should they continue with their current traditional fuel strategies until legal requirements are fully established?

1.4.2. Marketing Research Problem (MRP)

What is the role of industry stakeholders' perceptions of sustainable fuels, their price sensitivity, and current financial constraints in hindering their intention to purchase green fuels?

1.5. Broad Statement

Understanding the maritime industry's stance on sustainable fuel trade and the economic barriers that hinder this preference.

1.5.1. Specific Components

Component 1 - Perceptions

• How do industry professionals define sustainable bunker fuels, and how reliable do they consider these fuels to be?

• How do professionals perceive the transition process to alternative fuels?

Component 2 - Purchase Intention

• What are the main factors influencing shipowners' intentions to choose sustainable fuels?

• How does price sensitivity shape the decision to purchase green fuels?

Component 3 - Barriers to Purchase

• What are the main barriers (cost, lack of information, current fleet structure, etc.) that make it difficult for industry stakeholders to choose sustainable fuels?

• What is the impact of external economic factors on these choices?

1.5.2. Symptoms vs. Underlying Causes

1.5.2. Symptoms vs. Underlying Causes Table

Symptoms (Visible Issues)	Underlying Causes (Real Issues)
• Low market demand for sustainable fuels.	• The significant use difference between conventional and green fuels (Green Premium).
• Slow progress in converting existing fleets to alternative fuels.	• Declining investment capacity due to low freight rates and high financing costs.
• Industry stakeholders are adopting a "wait and see" strategy towards new regulations.	• Uncertainty and risk perception regarding the technological future of alternative fuels.
• Failure to achieve the expected momentum in environmental fuel targets.	• The complexity of regulations and the lack of expert human resources to manage this transition.

2. APPROACH TO THE PROBLEM

2.1. Type of Fieldwork (Qualitative Research - In-depth Interviews)

In this study, "In-depth Interview" was selected as the data collection method. The greatest advantage of this method is that it allows each participant to freely and thoroughly convey the technical details and concerns within their area of expertise (operational, academic, or commercial) without group pressure.

2.2. Sample Size

A total of 14 in-depth interviews will be conducted as part of the research. Participants have been divided into four main groups representing different segments of the industry.

2.3. Sampling Technique

The "Purposive/Judgmental Sampling" method will be used in selecting participants. This method will enable us to reach the "key individuals" with the highest technical knowledge from each group.

2.4. Sample Characteristics

The sample structure consists of 4 groups to reflect technical depth:

- Group 1: Senior Crew: Experienced Chief Engineers (Traditional system experience).

- Group 2: Junior/Next Gen Crew: Young officers who are more receptive to new technologies and keep up to date with digitalization and green energy training.
- Group 3: Academic Experts: Academics who have worked on decarbonization and new fuel technologies in academia.
- Group 4: Strategic Decision Makers: Technical department and Bunker Broker/Traders (Commercial and strategic decision makers).

2.5. Research Instrument (In-depth Interview Guide)

The questions to be asked of participants during the interviews are as follows:

2.5 Research Instrument Table

SECTION	QUESTIONS	REFERENCE(S)
Introductory Question	What are your general views on the decarbonization process in the maritime sector and the IMO's 2030/2050 targets?	-
Introductory Question	On a scale of 1 to 10, how would you rate your level of readiness for the transition to alternative fuels in your area of expertise?	-
Main Question	Do you think the operational safety risks (toxicity, flammability) of new generation fuels (ammonia, methanol, etc.) can be adequately managed in the field?	DNV (2024) - Maritime Forecast to 2050
Main Question	How does the reporting burden imposed by technical regulations affect the crew's primary focus on operational safety?	Hetherington, Flin & Adams (2006) - "Safety in shipping: The human element."
Main Question	How much of an obstacle is the lack of port infrastructure in fuel selection and refueling?(1-5)	Eurostat (2025) - "Maritime Transport Statistics"
Main Question	Do you think the personnel in the sector have the competence to manage this transition? Is the training curriculum keeping pace with the sector?	IMO (2024) - "Review of the STCW Convention"
Main Question	How do you assess the balance between the complex technical procedures required by new generation fuels and the current workload of personnel? How do you think these new operational burdens affect the quality of safety protocols?	-

Main Question	How do you observe the conflict between the experience-based reservations of older chief engineers and the curiosity of younger officers about technology in the field?	BIMCO (2021) - "Seafarer Workforce Report"
Main Question	What is the biggest "theory vs. practice" difference encountered in the actual use of fuels defined as "safe" in academic literature?	IMO (2023) - "Comprehensive Impact Assessment of Mid-term Measures"
Main Question	How do the logistical challenges during refueling affect your workload?	-
Main Question	What is the biggest disconnect between theoretical studies (IMO rules) and practical application (fuel replenishment)? Can you briefly summarize it?	-
Main Question	Should "cost-effectiveness" or "zero-risk safety" be the priority?	Psaraftis, H. N. (2019). "Sustainable Shipping: A Multi-Disciplinary View
Main Question	What will determine the pace of the transition to new generation fuels: technology, new ship/machine capital, or human resource training?	Poulsen, R. T., et al. (2022). "Green shipping transitions: On the line between technology and human agency."
Conclusive Questions	What does "perfect fuel" mean to you?	-
Conclusive Questions	In academic studies, what do you think is the biggest technical and psychological obstacle to the field (onboard) applicability of alternative fuels (especially ammonia and methanol) that are defined as safe?	DNV (2024) - "Maritime Forecast to 2050"
Conclusive Questions	Do you think that the concerns of ship workers are sufficiently taken into account by strategic decision-makers during this process?	Bennett, P. (2023). "The Human Element in Maritime Decarbonization: A Just Transition for Seafarers."

Methodological Note: The questions in this interview guide were structured by the researcher to meet the project's specific needs, drawing on the current literature and academic sources reviewed. During the design phase of the questions, methodological support was also obtained from artificial intelligence tools (generative artificial intelligence) to target gaps in the literature. The questions have not been directly quoted from any institution, organization, or printed work; they have been derived from the areas of expertise of professionals in the field (academics, crew, traders).

2.6. Ethical Considerations

This study is conducted in accordance with academic integrity and ethical research standards. The following principles are strictly followed to ensure the protection of the participants and the reliability of the data:

- **Informed Consent:** All participants (seafarers, bunker traders, and academics) are informed about the purpose of the research, the data collection process, and how the results will be used before the interviews begin. Verbal or written consent is obtained from each participant.
- **Voluntary Participation:** Participation in this study is entirely voluntary. Participants have the right to withdraw from the interview or refuse to answer any specific question at any time without any negative consequences.
- **Data Security:** All interview recordings and notes are stored securely and used solely for academic purposes within the scope of this project. The raw data will not be shared with third parties or used for commercial gain.
- **Academic Integrity:** As noted in the methodology, while AI tools were utilized for literature synthesis and drafting research instruments, the final analysis and conclusions are the original work of the researcher, supported by cited academic literature.

3. RESEARCH FINDINGS

3.1 Descriptives

This section presents the demographic and professional profiles of the participants involved in the study. A total of **14 participants** were interviewed to gather diverse perspectives on the transition to sustainable bunker fuels in the maritime industry. To maintain ethical standards and confidentiality, all participants are referred to by codes (e.g., P1, P2, ..., P14).

The study reached a specialized group of male professionals (n=14) representing different pillars of the maritime sector. The following table illustrates the descriptive characteristics of the research sample:

3.1 Descriptive Table:

Characteristics	Category	Number of Participants (n)
Gender	Male	14
	Female	0
Professional Role	Chief Engineers	4
	Academic Professionals	4
	Interns (Deck/Engine)	4
	Bunker Department Specialist	1
	Technical Department Specialist	1
Professional Experience	Entry Level (Interns)	4
	Experienced (5 - 30 Years)	10
Total		**14**

The sample distribution ensures a balanced view by including both the decision-making "technical and administrative" layers (Chief Engineers, Bunker and Technical Specialists), the "theoretical" layer (Academics), and the "future workforce" (Interns). While the interns represent the initial stage of maritime careers, the majority of the participants (71%) possess significant industry experience ranging

from 5 to 30 years, providing deep insights into the sector's evolution and its readiness for decarbonization.

3.2. Thematic Analysis

The findings from the interviews were analyzed by categorizing the **16 questions** into four main thematic pillars. This ensures that every aspect of the maritime decarbonization process—from operational safety to strategic decision-making—is addressed based on participant feedback. This part of the project was supported by artificial intelligence tools.

3.2 Thematic Analysis Table:

Categories&Questions	Sub-Theme	Participants' Detailed Opinions & Quotations
CATEGORY 1: Operational Safety & Technical Readiness		
RQ3: Operational Safety Risks	Toxicity & Flammability	The health risks associated with 'zero-emission' fuels are undeniable. Instead of an immediate and risky leap, a 'Blue Transition'—where current fuels are blended with alternative ones—would be a far more sustainable and practically applicable path for the industry." (P7, Academic)
RQ4: Reporting Burden	Administrative Overload	Most of the emissions and compliance reports are not handled by senior personnel; instead, they are delegated to us interns. We spend so much time dealing with this paperwork that we are losing the opportunity to actually learn the technical aspects of the job. (P12, Intern)
RQ9: Theory vs. Practice Gap	Academic vs. Onboard	There is a massive uncertainty regarding the insurance and liability of these new fuels. If a major technical failure occurs due to alternative fuel usage at sea, it is unclear whether insurance companies will cover the damages. Everything is still in a gray area. (P14, Technical Manager)
RQ11: Bunkering Disconnect	IMO vs. Onboard	In practice, not every port operates according to these global IMO standards. There is a huge gap between international regulations and local port realities." (P4, Chief Engineer)
RQ15: Technical & Psych. Barriers	Crew Psychology	The lack of specialized training creates a deep-seated fear among the crew regarding these new fuels. This ignorance doesn't just lead to technical errors; it creates a constant

		psychological pressure and anxiety on board. (P10, Senior Academic)
CATEGORY 2:Workforce Readiness & Competency		
RQ2: Readiness Level (1-10)	Perception of Preparedness	The calculated average readiness score of the participants is **4.43 out of 10**, indicating a critical gap between global decarbonization targets and the actual technical/human capacity currently available in the industry.
RQ6: Workforce Competency	Training Quality	Current candidates in marine engineering are not receiving an education that aligns with these rapid updates. There is a fundamental mismatch between the university curriculum and the evolving technical requirements of new-generation fuel systems. (P8, Academic)
RQ7: Workload vs. Safety	Operational Balance	These complex reports cause so much confusion that I am becoming unable to understand the actual technical work I am supposed to learn. Ultimately, it is destroying my motivation to pursue a career at sea. (P11, Intern)
RQ8: Generational Conflict	Experience vs. Technology	The younger generation is naturally more tech-savvy. However, they struggle with patience and long-term focus—qualities that, unfortunately, are not highly prioritized by them but are essential for engine room operations.(P5, Chief Engineer)
RQ13: Transition Process	Tech vs.Education vs. Human Resources	The financial aspect is the true engine of change. According to our findings, **64.3%** of participants identify **Capital** as the primary driver, while **21.4%** emphasize **Education** and only **14.3%** point to **Technology**. It is clear that without funding, the transition stops.
CATEGORY 3: Infrastructural & Economic Barriers		
RQ5: Port Infrastructure	Port-Fuel Supply	The average score for infrastructure readiness is 1.28 out of 5, which clearly indicates that the global port infrastructure is critically unprepared for the transition.

RQ10: Logistical Challenges	Operational Stress	The logistical complexities and uncertainties in the refueling process are having a completely negative impact on the entire transition. (P6, Chief Engineer)
RQ12: Cost vs. Safety	Priority Conflict	Regardless of the financial pressure of the transition, 92.8% of our participants (13 out of 14) emphasize that 'Safety First' must remain the non-negotiable priority.
RQ14: The Perfect Fuel	Fuel Definition	My definition of the perfect fuel is one that requires no modifications to the machinery, has a low carbon footprint in the supply chain, and is readily available to the shipowner whenever needed. (P1 Bunker Trader Manager)
CATEGORY 4: Strategic Governance & Crew Welfare		
RQ1: General views on IMO 2030/2050	Global Vision vs. Reality	Vessels built or to be built with next-generation engines are no longer an option but an absolute necessity (essential) for all fleets. To remain competitive and compliant, the transition to these new technologies is inevitable." (P14, Technical Manager)
RQ16: Inclusion in Decisions	Crew Voice	There is a **100% consensus** among participants that crews' opinions are entirely disregarded. Decisions are made without consulting the people who will actually operate these new technologies.

4. DISCUSSION

This section is presented for evaluation under three main headings: "literature vs. research findings".

1. **Implementation & Readiness Gap**

   The literature states that the IMO 2023 Strategy and other sources indicate that technological transformation has begun rapidly, and the sector is mobilizing to achieve the 2030 and 2050 targets.

   Research Findings state: However, in this study, participants' preparation score was 4.43/10 (Q2). Contrary to the optimism in the literature, professionals in the field find these goals unrealistic or very challenging due to "significant capital requirements and decreasing time" (Q1). They specifically noted that finding significant capital for this transition process is difficult in the Turkish market.

2. **The Infrastructure "Deal-Breaker."**

   Literature states: Academic studies (e.g., DNV Maritime Forecast 2050) predict that ports and bunkering facilities can develop in parallel with ship technologies.

Research findings indicate that the participants' infrastructure obstacle score was 1.28/5 (Q5 - 1: Major Obstacle). In other words, while the literature suggests the issue is "being resolved," chief engineers in the field state that logistical challenges "completely negatively impact" the process (Q10) and that ports are not physically ready for this transition.

3. **The Human Element & Education**

Literature says: The literature argues that with digitalization and green transformation, seafarers will gain new competencies and the nature of the job will "improve".

Research Findings say: Our findings show with 100% agreement (Q16) that the opinions of seafarers are not taken into account. Furthermore, the increasing reporting of trainees leading to "disinterest in sea" (Q7) and the curriculum failing to keep pace (Q6) demonstrate that what the literature calls "just transition" is a "disconnect" in practice.

5. CONCLUSION

5.1 Summary of the Research

The main purpose of this research was to go beyond the official reports and look at the real-world practicality of the maritime industry's shift toward alternative fuels. While international bodies like the IMO set very ambitious goals for 2030 and 2050, we wanted to hear the perspective of the people who actually "live" the industry. To achieve this, we conducted interviews with 14 stakeholders, including technical managers who handle the budgets, chief engineers who run the engines, and even interns who represent the future of the profession.

Our findings suggest that there is a deep-seated "reality gap" in the sector. When we asked participants to rate the industry's readiness, the average score came out to a disappointing **4.43 out of 10**. This number alone tells us that the confidence level is quite low. Throughout the study, we identified three or four main themes that explain this skepticism. First, the financial burden is enormous. As one Technical Manager mentioned, next-generation vessels are now "essential" for a fleet's survival, yet the capital required to build or retrofit these ships is massive, and the time left to do so is shrinking every day.

One of the most striking parts of the data was related to port infrastructure. On a scale where 1 represents a major barrier, the average score was a shocking **1.28**. This shows that most professionals see the lack of bunkering stations and logistical readiness at ports as a "deal-breaker." It's not enough to have a ship that runs on green fuel if there is nowhere to refuel it reliably. This creates what we might call a "logistical paralysis" that could stop the transition in its tracks before it even really starts.

Furthermore, we looked at the "human side" of the coin, which is often ignored in technical papers. Our research highlighted a clear "Curriculum Lag" in maritime schools. It seems that the education system is struggling to keep up with how fast technology is moving. This doesn't just affect knowledge; it affects morale. We spoke with junior officers and interns who expressed a sense of burnout and loss of motivation, partly because of the overwhelming paperwork and the feeling that they are not being prepared for the "new" maritime world. Perhaps the most telling result was the **100% agreement** among our 14 participants that seafarers' opinions are rarely asked for during these big transitions.

In conclusion, this research summarizes that while the maritime industry is trying to move forward, it is currently doing so with a "top-down" approach that ignores logistical realities and the human element.

The transition is being driven by capital and regulations, but for it to be truly successful and sustainable, the industry needs to fix the infrastructure gap and start listening to the people on the ships.

5.2 Implications

This section discusses the broader impact of our findings. The results of this study go beyond just numbers; they provide a roadmap for both the academic world and the leaders of the maritime industry.

5.2.1 Academic Implications

From a scholarly perspective, this research highlights a significant gap in current maritime literature. While most academic papers focus heavily on the "engineering" or "chemistry" side of alternative fuels, our findings suggest that the "human and educational" side is equally critical.

Firstly, the concept of **"Curriculum Lag"** identified in this study serves as a warning for maritime academies. Our data shows that theoretical education is not moving as fast as industry technology. Academics need to shift their focus toward creating more dynamic, "tech-ready" training modules. Secondly, this research adds to the literature by proving that decarbonization is not just a technical change but a psychological and organizational one. Future studies should look more into "crew retention" and "mental burnout" during technological shifts, as these were major concerns raised by our participants. We are suggesting that the "Human Element" should no longer be a secondary topic in maritime research but a primary one.

5.2.2 Practical and Managerial Implications

For the people running the industry—the managers and shipowners—the implications are even more direct. The study clearly shows that money alone cannot buy a successful transition.

One of the key takeaways for management is the need to move away from a **"Top-Down" decision-making style**. Since **100% of our participants** felt ignored, managers should consider creating "feedback loops" where captains and engineers can share their practical experiences with new fuels before the company makes a million-dollar investment.

Also, the extremely low infrastructure score (**1.28**) tells managers that they need to be very cautious with their investment timelines. Instead of just buying a green ship, they need to invest in strategic partnerships with ports and fuel suppliers to ensure their fleet doesn't end up "stranded." Lastly, for HR managers, there is a clear message: the younger generation (interns and junior officers) is losing motivation. To keep the best talent, companies must provide better support and reduce the administrative "paperwork" burden that comes with new environmental regulations. Managers or similar industry leaders can use these insights to build more resilient and human-centered decarbonization strategies.

5.3 Limitations and Future Research Directions

Every research project has its boundaries, and this study is no exception. Acknowledging these limitations is not a sign of weakness; rather, it provides a clearer context for the findings and opens new doors for future scholars who wish to dive deeper into the maritime transition.

The primary **limitation** of this study is its sample size. While the 14 participants provided incredibly rich and high-quality "insider" information, they represent only a small segment of the global maritime community. Most of our stakeholders were based in Turkey or worked for Turkish-linked companies. Therefore, the results—especially regarding infrastructure scores—might reflect local or regional frustrations more than a global average. Additionally, because the interviews were conducted during a period of rapid regulatory change, the participants' views might be influenced by current market pressures and temporary economic uncertainties.

Regarding **future research directions**, there is a lot of ground still to cover. First, since our study found a **100% consensus** that seafarers are being ignored, a future project could focus exclusively on a larger group of active crew members across different nationalities to see if this feeling of exclusion is truly global. Secondly, it would be very valuable to conduct a longitudinal study—meaning, following **a major shipowning group** over several years—to see how their management strategies for alternative fuels actually affect crew motivation. Finally, future researchers might want to explore the "Curriculum Lag" more deeply by comparing maritime university syllabuses with the actual technological requirements of modern "next-generation" vessels. This could help create a more standardized and effective training model for the 2050 era.

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7. APPENDIX

Appendix A: Interview Instruments (PowerPoint Presentation)

- **Presentation Title:** Sustainable Bunker Usage in Maritime: Assessing the Strategic Shift Towards Low-Carbon Alternative Fuels
- **Content:** The PowerPoint presentation used during online interviews included 10 slides covering IMO 2030-2050 targets, curriculum, and the visual comparison of alternative fuel storage requirements. This visual aid was used to ensure participants had a standardized understanding of the technical problems before providing their insights.