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WINDS OF CHANGE: DETERMINANTS OF DECARBONIZATION INITIATIVE ADOPTION IN THE SHIPPING SECTOR WITH FIRM SIZE AS A MODERATOR

Mohamed M. Galal Tawfik
ESLSCA University, Giza, Egypt
E-mail: mohamed.tawfik21bg@eslsca.edu.eg

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Abstract

The shipping industry, which accounts for approximately 3% of global greenhouse gas emissions, faces substantial challenges in adopting the Global Decarbonization Initiative to meet the International Maritime Organization's net-zero target by 2050. This study examines the influence of customer demand, green finance, regulatory frameworks, operational efficiency, technological efficiency, and sustainable energy on the adoption of decarbonization practices, with firm size as a moderating variable. Employing a mixed-methods approach, the research combines six stakeholder interviews with a survey of 90 employees from various shipping firms conducted between 2024 and 2025.The findings reveal that operational and technological efficiencies are the strongest drivers of decarbonization adoption, followed by regulatory frameworks, sustainable energy, green finance, and customer demand. Firm size significantly moderates these relationships, with larger firms being more capable of implementing sustainable practices. Based on these results, tailored strategies are recommended: larger firms should spearhead technological innovation, while smaller firms require targeted support through green finance mechanisms. Limitations of the study include its cross-sectional design and reliance on convenience sampling, highlighting the need for future longitudinal and geographically diverse research.

Keywords: decarbonization, shipping industry, green finance, regulatory frameworks, operational efficiency, technological efficiency, sustainable energy, firm size.

1. INTRODUCTION

The shipping industry, which handles approximately 80% of global trade by volume, is a vital driver of economic development but also contributes 3% of global greenhouse gas (GHG) emissions—placing it among the world's top 10 emitters (Grzelakowski, 2022). In response, the International Maritime Organization (IMO) adopted the 2023 Revised GHG Strategy, with indicative checkpoints to reduce total annual GHG emissions by at least 20% (striving for 30%) by 2030 and at least 70% (striving for 80%) by 2040 (relative to 2008 levels), aiming for net-zero GHG emissions by or around 2050, in alignment with the Paris Agreement's 1.5°C goal. Recent developments—such as the inclusion of shipping in the European Union Emissions Trading System (EU ETS), which began applying to maritime emissions from January 2024, with a phased implementation (40% of emissions in 2024, 70% in 2025, and 100% from 2026), and trials of alternative fuels like ammonia and methanol—signal progress. However, significant challenges remain, including technological readiness, infrastructure constraints, and the high estimated cost of decarbonization, estimated at approximately USD 1–2 trillion by 2050 (e.g., UMAS, Global Maritime Forum, & Energy Transitions Commission, 2020).

The scientific recognition of anthropogenic climate change, reinforced by the Intergovernmental Panel on Climate Change (IPCC) reports from 1990 onward, led to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and the Kyoto Protocol in 1997. International shipping and aviation emissions were treated differently from land-based sources and assigned to the IMO and ICAO respectively for technical regulation. Although the 2015 Paris Agreement does not explicitly mention shipping, the IMO has consistently aligned its work with Paris goals, as acknowledged during MEPC 69 in 2016 (International Maritime Organization, 2016).

Previous research has predominantly focused on developed economies, often neglecting the unique constraints of resource-limited regions (Mallouppas, 2021). This study addresses this gap by examining six key drivers of decarbonization adoption—customer demand, green finance, regulatory frameworks, operational efficiency, technological efficiency, and sustainable energy—while considering the moderating effect of firm size. Employing a mixed-methods approach, we integrate qualitative stakeholder insights with quantitative survey data to explore the following research question: What factors influence the adoption of the Global Decarbonization Initiative in the shipping industry, and how does firm size moderate these relationships?

2. LITERATURE REVIEW

2.1 Theoretical Foundation

This study integrates three complementary lenses: Resource-Based View (RBV) explains internal capability differences, Stakeholder Theory highlights external pressures (especially from customers), and Institutional Theory accounts for coercive, normative, and mimetic pressures from regulations and industry peers. The combination is particularly suitable for examining firm size moderation because larger firms typically possess superior resources (RBV), greater exposure to stakeholder demands, and higher visibility to institutional pressures (DiMaggio & Powell, 1983; Zhang, 2022).

2.2 Synthesis of Extant Findings and Identified Gaps

While some studies report strong customer-driven decarbonization (Wang et al., 2018), others find limited willingness to pay green premiums in price-sensitive bulk shipping segments (Poulsen & Sampson, 2020). Similarly, technological efficiency is frequently cited as critical (Kumar & Patel, 2024), yet high upfront costs create

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adoption barriers, especially for SMEs (Nisiforou & Papadopoulos, 2022). These contradictory findings underscore the need for contextual moderators such as firm size.

Customer Demand. Stakeholder Theory emphasizes the role of external stakeholders, particularly customers, in driving organizational change (Brown and Taylor, 2024). In shipping, customer demand for sustainable practices is growing, with 71% of companies willing to pay premiums for carbon-neutral shipping (Koilo, 2024). This demand pressures firms to adopt green practices to maintain competitiveness, particularly in markets with environmentally conscious consumers. However, the influence of customer demand varies by firm size, as larger firms may have more resources to respond to such pressures (Wang et al., 2018). Thus, customer demand is expected to positively influence decarbonization adoption, with firm size moderating this relationship. Accordingly, it is argued that

H1: Customer demand is positively associated with decarbonization adoption Green Finance. RBV highlights the importance of financial resources for adopting sustainable technologies (Barney, 1991). Green finance, through mechanisms like the Poseidon Principles, supports investments in low-carbon technologies, with an estimated USD 1–2 trillion needed by 2050 (e.g., UMAS, Global Maritime Forum, & Energy Transitions Commission, 2020). Access to green bonds and loans enables firms to fund costly transitions, but smaller firms often face barriers due to limited financial capacity (Zhang, 2022). Firm size thus moderates the impact of green finance on decarbonization efforts. Hence, it is hypothesized:

H2: Green finance is positively associated with decarbonization adoption. Regulatory Frameworks. Institutional Theory underscores the role of regulatory pressures in shaping organizational behavior (Greenwood et al., 2023). The IMO’s GHG Reduction Strategy and the EU ETS (which began applying to shipping in 2024) enforce compliance through carbon pricing and emission limits. However, global regulatory inconsistencies create challenges, particularly for smaller firms with fewer resources to navigate complex compliance requirements (Koilo, 2024). Firm size is expected to moderate the influence of regulatory frameworks on decarbonization adoption. Therefore, it is hypothesized:

H3: Regulatory frameworks are positively associated with decarbonization adoption Operational Efficiency. RBV posits that operational capabilities enhance competitive advantage (Barney, 1991). In shipping, operational efficiency, achieved through digital route optimization and data analytics, reduces fuel consumption and emissions (IRENA, 2022). Larger firms, with greater access to advanced systems, are better positioned to implement these practices, suggesting a moderating role of firm size (Zhang, 2022). Operational efficiency is thus a critical driver of decarbonization. Accordingly, it is argued that

H4: Operational efficiency is positively associated with decarbonization adoption. Technological Efficiency. Technological advancements, such as methanol fueled engines, are central to decarbonization but require significant investment (Kumar and Patel, 2024). RBV suggests that firms with superior technological resources gain a competitive edge (Barney, 1991). Larger firms, with greater RD budgets, are more likely to adopt these innovations, moderating the relationship (Nisiforou and Papadopoulos, 2022). Technological efficiency is expected to significantly influence decarbonization adoption. Thus, it is hypothesized that: H5: Technological efficiency is positively associated with decarbonization adoption. Sustainable Energy. The transition to sustainable energy sources, such as biofuels and hydrogen, is critical for decarbonization but limited by infrastructure availability (Nisiforou and Papadopoulos, 2022). Institutional Theory highlights external pressures for adopting renewable energy, while RBV emphasizes the need for resources to overcome infrastructure gaps (Barney, 1991). Larger firms are better equipped to invest in sustainable energy, moderating its impact on decarbonization (Zhang, 2022). Thus, it is argued that:

H6: Sustainable energy adoption is positively associated with decarbonization adoption. Firm size plays a moderating role in the relationship between key drivers—such as sustainable energy technological efficiency, operational efficiency, regulatory frameworks, green finance, and customer demand—and the adoption of decarbonization practices. Larger firms often possess greater financial resources, technical expertise, and organizational capacity, enabling them to more effectively capitalize on technological advancements, comply with regulatory demands, and respond to customer preferences for sustainable practices. Conversely, smaller firms may face resource constraints that limit their ability to implement decarbonization strategies despite similar external pressures or opportunities. Therefore, the positive effects of these drivers on decarbonization adoption are likely to be stronger and more pronounced in larger firms, highlighting the importance of firm size as a critical contextual factor in sustainability transitions. Therefore, it is argued that Firm size positively moderates the relationship between (a) sustainable energy technological efficiency, (b) operational efficiency, (c) regulatory frameworks, (d) green finance, (e) customer demand, and decarbonization adoption, such that the positive effect of each factor on decarbonization adoption is stronger for larger firms compared to smaller firms.

H7: Firm size positively moderates the relationship between (a) customer demand, (b) green finance, (c) regulatory frameworks, (d) operational efficiency, (e) technological efficiency, (f) sustainable energy and decarbonization adoption.

3. METHODOLOGY

3.1 Research Design

Sequential explanatory mixed-methods design (QUAL → quant). Semi-structured interviews (Phase 1) informed survey development (Phase 2), with quantitative results explained by qualitative insights (Creswell & Plano Clark, 2018).

3.2 Qualitative Phase

Six senior stakeholders (3 shipowners, 2 operators, 1 regulator) were purposively selected. Interviews (45–70 min) were conducted via Zoom, recorded, and transcribed verbatim. A semi-structured guide with 17 open-ended questions was used (provided in Appendix A). Thematic analysis followed Braun & Clarke (2006); two independent coders achieved 89% agreement (Cohen's $\kappa = 0.84$); discrepancies were resolved by the first author. Saturation was reached after the fifth interview.

3.3 Quantitative Phase

Survey respondents: 90 professionals (38% senior management, 44% middle management, 18% technical/operational staff) from shipping firms with primary operations across global regions (North America 30%, Asia 27.8%, South America 18.9%, Europe 15.6%, Africa 7.8%). Firm-size distribution: <250 employees (34%), 250–1000 (28%), >1000 (38%). Convenience and snowball sampling were used due to restricted industry access; this *approach, while enabling access to a diverse sample, may introduce selection bias, limiting generalizability as it does not ensure representativeness (Creswell, 2022). No significant bias was detected in firm size distribution, but overrepresentation from North America (30%) should be noted.*

3.4 Measures

All multi-item scales (4 items each) were adapted from Wang et al. (2018), Xue Lai (2023), and Koilo (2024). Sample items are provided in Appendix B. *Firm size was measured as a single item (self-reported on a 5-point scale); this limitation is acknowledged, and future studies should use multi-item or objective measures (e.g., employees, revenue).* Reliability: Cronbach's α 0.75–0.93; CFA fit: $\chi^2/df = 1.62$, CFI = 0.96, RMSEA = 0.056.

3.5 Analytical Approach Common method bias: Harman's single-factor test (36.4% variance explained < 50%); marker variable technique showed non-significant correlations. Multicollinearity: all VIF < 2.8. Nonresponse bias was assessed by comparing early and late respondents; no significant differences were found ($p > 0.05$). Moderation tested using hierarchical regression with interaction terms; slopes analyzed for high/low firm size.

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4. RESULTS

4.1 Descriptive Statistics and Correlations

Table 1: Descriptive Statistics and Correlations

Variable	Mean	SD	1	2	3	4	5	6	7	α
1. Customer Demand	3.22	0.9	-							0.8
2. Green Finance	3.58	0.7	0.45**	-						0.8
3. Regulatory Framework	3.65	0.8	0.52**	0.49**	-					0.9
4. Operational Efficiency	3.73	0.8	0.48**	0.51**	0.55**	-				0.9
5. Technological Efficiency	3.65	0.8	0.50**	0.47**	0.53**	0.60**	-			0.9
6. Sustainable Energy	3.39	0.8	0.42**	0.44**	0.46**	0.49**	0.51**	-		0.9
7. Decarbonization Adoption	3.61	0.8	0.34**	0.33**	0.71**	0.75**	0.76**	0.62**	-	0.9
8. Firm Size	3.78	1	0.25*	0.28*	0.30**	0.32**	0.35**	0.27*	0.40**	-

p < 0.01, *p < 0.05

4.2 Hypothesis Testing

Table 2: Multiple Regression Analysis

Predictor	**β**	**SE**	**t**	**p**	**95% CI**	**Partial η²**
Customer Demand	0.155	*0.067*	2.313	0.023	[0.022, 0.288]	*0.06*
Green Finance	0.254	*0.088*	2.878	0.005	[0.079, 0.429]	*0.09*
Regulatory Framework	0.267	*0.102*	2.61	0.011	[0.064, 0.470]	*0.07*
Operational Efficiency	0.309	*0.123*	2.508	0.014	[0.065, 0.553]	*0.07*
Technological Efficiency	0.295	*0.119*	2.468	0.016	[0.059, 0.531]	*0.07*
Sustainable Energy	0.201	*0.087*	2.31	0.023	[0.028, 0.374]	*0.06*

Model: $R^2 = 0.69$, Adjusted $R^2 = 0.68$, $F = 30.01$, $p < 0.01$, VIF range 1.5-2.8

4.3 Moderation Results

Table 3: Moderation Analysis

Relationship	Interaction β	ΔR²	p	Simple Slope (High Firm Size)	Simple Slope (Low Firm Size)
Customer Demand × Firm Size	0.2	0.1	0.01	0.49	0.09
Green Finance × Firm Size	0.14	0	0.02	0.48	0.2
Regulatory Framework × Firm Size	0.16	0.1	0	0.86	0.54
Operational Efficiency × Firm Size	0.13	0	0	0.86	0.6
Technological Efficiency × Firm Size	0.12	0	0	0.76	0.52
Sustainable Energy × Firm Size	0.12	0	0.03	0.69	0.45

The moderation analysis (Table 3) shows significant interaction effects for all six predictors with firm size (all $p \leq 0.03$), indicating that firm size strengthens the positive relationships between the drivers and decarbonization adoption. Figure 1 (in Appendix C) illustrates these interaction plots, depicting the simple slopes at high and low levels of firm size. The steeper slopes for high firm size demonstrate that larger firms are better able to translate operational efficiency, technological efficiency, regulatory frameworks, green finance, sustainable energy, and customer demand into decarbonization practices compared to smaller firms.

4.4 Integration of Qualitative Findings

Table 4: Linking Interview Themes to Survey Constructs

Interview Theme	Example Quote	Linked Survey Construct	Quantitative Significance
Operational Challenges	"Infrastructure gaps are major barriers"	Operational Efficiency	$\beta = 0.73$, $p < 0.01$
Regulatory Inconsistencies	"Global standards need harmonization"	Regulatory Framework	$\beta = 0.70$, $p < 0.01$
Technology Adoption	"AI and alternative fuels are key"	Technological Efficiency	$\beta = 0.73$, $p < 0.01$
Finance Barriers	"Smaller firms struggle with funding"	Green Finance	$\beta = 0.34$, $p < 0.01$
Customer Pressures	"Clients demand green options"	Customer Demand	$\beta = 0.29$, $p < 0.01$
Sustainable Energy	"Biofuels and hydrogen are future"	Sustainable Energy	$\beta = 0.57$, $p < 0.01$

5. DISCUSSION

Operational and technological efficiencies emerged as the strongest drivers of decarbonization, consistent with studies on AI-driven route optimization and alternative fuel adoption (IRENA, 2022); (Kumar and Patel, 2024). Regulatory frameworks, reinforced by EU ETS inclusion for shipping starting in 2024, are pivotal, though global inconsistencies pose challenges (Greenwood et al., 2023). Sustainable energy and green finance are essential but limited by infrastructure and funding gaps, respectively. Customer demand has a weaker influence, indicating the need for economic incentives to bridge the projected 15% cost gap by 2050 (Koilo, 2024).

The weak role of customer demand ($\beta = 0.29$) may stem from price-sensitive segments where willingness to pay premiums is limited, as noted in contradictory findings (Poulsen & Sampson, 2020; Acciaro et al., 2023). Firm size significantly moderates all relationships, with larger firms leveraging resources for innovations like methanol trials (Nisiforou and Papadopoulos, 2022), while smaller firms rely on green finance (Xue Lai, 2023). This supports RBV's focus on resource disparities (Zhang, 2022) and Stakeholder Theory's emphasis on external pressures (Brown and Taylor, 2024). However, Institutional Theory is challenged by regulatory lags, necessitating harmonized global standards (Greenwood et al., 2023)

While operational and technological efficiencies emerged as the strongest predictors in our sample, their dominance may be context-specific and should not be universally generalized given the modest sample size.

5.1 Theoretical Contributions

This study integrates RBV, Stakeholder Theory, and Institutional Theory, proposing a scale-adjusted sustainability framework that accounts for firm size moderation. This extends existing models by addressing resource constraints in diverse contexts, a gap in 2025 literature.

5.2 Practical Implications

Managers should prioritize operational efficiencies (e.g., digital route optimization) and comply with EU ETS regulations for shipping (phased in from 2024). Larger firms should lead in adopting ammonia-fueled engines, while smaller firms should seek green finance via partnerships. Collaborative initiatives, like the Sea Cargo Charter, can enhance synergies.

5.3 Limitations

The cross-sectional design and convenience sampling (90 respondents) limit generalizability (Creswell, 2022). Self-reported data risks bias, and the single-item firm size measure oversimplifies the construct. Global sample with diverse regional representation but without stratified sampling, potentially overlooking specific cultural or economic disparities in underrepresented areas (e.g., Africa at only 7.8%) (Khan, 2023). Potential common method variance, although tests were non-significant.

5.4 Future Research

Longitudinal studies post-2025 with larger, stratified samples (e.g., 200 firms) could assess IMO policy impacts. Exploring cultural influences and supply chain emissions (targeting 30% reduction by 2030) would enhance generalizability. Emerging technologies like hydrogen and carbon capture warrant investigation.

6. CONCLUSION

Operational and technological efficiencies are the primary drivers of decarbonization in the shipping industry, followed by regulatory frameworks, sustainable energy, green finance, and customer demand. Firm size moderates these relationships, with larger firms better equipped for sustainable practices. Tailored strategies—technological innovation for larger firms and green finance for smaller firms—are critical for achieving IMO's net-zero target by 2050. Regulatory compliance and collaboration are essential. Future research should address regional disparities and longitudinal trends to support a sustainable maritime future.

Declarations

Authors declare that they have no conflicts of interest.

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