MASTER'S THESIS

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What Drives Shipowners' Decision to Adopt Energy Saving Technologies (ESTs) for Ship Retrofitting?

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Sammendrag

Den globale skipsfartsindustrien står overfor barrieren for utilstrekkelig innføring av tekniske ettermonteringstiltak fra rederier for energieffektiviseringsforbedring og utslippsreduksjon. Denne studien tar sikte på å undersøke driverne for vedtakelsen av skipsenergibesparende teknologier (ESTs) for skips ettermontering fra rederiets perspektiv.

Basert på rammen av teorien om planlagt atferd ble det utviklet og distribuert en online undersøkelse til rederier som har vedtatt ESTs globalt. Det ble gjennomført en kvantitativ analyse av undersøkelsesdataene for å undersøke sammenhengene mellom potensielle drivfaktorer og rederiers intensjon om å vedta EST-er for ettermontering av skip. Videre ble det gjennomført en statistisk analyse av databasen til World Fleet Register for å identifisere viktige skipsforhold som kunne gjøre det mulig for redere å vedta ESTs.

Funnene tyder på at EEXI-samsvar, konkurrenters adopsjon og økonomiske ressurser er tre hoveddrivere for rederier for å ettermontere skip med ESTs. I tillegg inkluderer andre kjørefaktorer bedre CII-resultater, drivstoffkostnadsreduksjon, kundenes krav og riktige skipsforhold. Når det gjelder riktige skipsforhold, indikerer resultatene at liten skipsalder og samsvar med spesifikke EST-er har et positivt forhold til rederiers vedtakelse av ESTs.

Studien er spesielt relevant for beslutningstakere og bedrifter som har som mål å akselerere spredningen av grønn teknologi og energieffektivisering i den globale maritime sektoren.

Preface

This master thesis marks the end of my master's study of global management at Nord University Business School. The past two years in the program have been filled with engaging lectures and exciting assignments with numerous learning and beautiful memories.

I am grateful for undertaking the research project on shipowners' adoption of ship energy-saving technologies, connected to Nord University's participation in the EU WASP (Wind Assisted Ship Propulsion) project. With the support from the Centre for High North Logistics and my supervisor Dr.Roberto, the period working on the research project has been exhilarating.

In the beginning, I would like to thank the Centre for High North Logistics for the research funding and stimulating research environment. I would also like to thank all the shipowners who have answered my survey and provided profound insights into the research. My gratitude also goes to the shipowners who have not answered the survey but emailed me valuable feedback, with which I would improve my data collection techniques in future research. Finally, my sincere thanks go to my supervisor Dr. Roberto Rivas Hermann, for providing his utmost proficient academic and professional support and guiding me through an orderly path in the research process.

Bodø, May 18, 2022

Abstract

The global shipping industry faces the barrier of insufficient adoption of technical retrofit measures by shipowners for energy efficiency improvement and emission reduction. This study aims to investigate the drivers of the adoption of ship energy-saving technologies (ESTs) for ship retrofitting from the perspective of shipowners.

Based on the framework of the theory of planned behavior, an online survey was developed and distributed to shipowners that have adopted ESTs globally. A quantitative analysis of the survey data was carried out to examine the relationships between potential driving factors and shipowners' intention to adopt ESTs for ship retrofitting. Furthermore, a statistical analysis of the database of the World Fleet Register was conducted to identify key ship conditions that could facilitate shipowners to adopt ESTs.

The findings suggest that EEXI compliance, competitors' adoption, and financial resources are three main drivers for shipowners to retrofit ships with ESTs. In addition, other driving factors found include better CII results, fuel cost reduction, clients' requirements, and right ship conditions. Concerning right ship conditions, the results indicate that small ship age and the match with specific ESTs have a positive relationship with shipowners' adoption of ESTs.

The study is especially relevant to policymakers and businesses that aim to accelerate the diffusion of green technologies and energy efficiency improvement in the global maritime sector.

Keywords: ship energy efficiency, energy-saving technologies (ESTs), retrofit

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ATT: Attitude

BV: Besloten Vennootschap (a private limited company commonly in Netherlands or Belgium)

CHNL: Centre for High North Logistics

CII: Carbon Intensity Indicator

CO_2: Carbon Dioxide

DNV: Det Norske Veritas

EEXI: Energy Efficiency Existing Ship Index

ESTs: Energy Saving Technologies

EU: European Union

IMO: International Maritime Organization

NO_X: Nitrogen Oxides

OECD: Organization for Economic Cooperation and Development

PBC: Perceived Behavioral Control

SO_X: Sulphur Oxides

SN: Subjective Norms

TPB: Theory of Planned Behavior

WASP: Wind Assisted Ship Propulsion

List of Appendixes

Chapter I: Introduction

1.1 Background

The international shipping industry undertakes around 90 percent of the global trade volume and remains a vital driving force for the world economy (OECD, 2022). However, its negative environmental and climate impacts remain a huge concern because of its high fossil fuel consumption and harmful emissions, e.g., NO_X at around 15% per year, SO_X at about 13% per year, CO_2 at around 3% per year (IMO, 2019b). Therefore, there is an urgent need for emission reduction and green transformation in the shipping industry.

Ship energy efficiency measures will play a central role in the coming years to achieve this goal. It is estimated that ships' emissions and fuel consumption could be reduced by up to 75 percent by applying energy efficiency measures (IMO, 2018), with technical retrofitting measures as an essential part.

Technologies have been a crucial driving force for revolution and change throughout history. The diffusion of ship energy-saving technologies (ESTs) is a critical part of the solution for energy efficiency improvement and green transformation in the shipping industry (IMO, 2011). Retrofitting ships with ESTs means less fuel consumption and harmful emissions. However, the reluctance of shipowners to adopt technical retrofit measures has become a barrier (Kaya & Erginer, 2021).

This thesis intends to find out the drivers of the adoption of energy-saving technologies (ESTs) for ship retrofitting from the perspective of shipowners, with an aim to accelerate the diffusion of green technologies and energy efficiency improvement in the global shipping industry, which fits in the big picture of combating climate and environmental challenges of our time.

1.2 Research Questions

Energy efficiency measures are robust solutions for emission reduction in the shipping industry (IMO, 2018). However, the low adoption rate of technical retrofit measures, i.e., adopting energy-saving technologies (ESTs) for ship retrofitting, has become a significant barrier to further energy efficiency improvement in shipping. Stevens et al. (2015) found that energy-efficiency initiatives by policymakers do not stimulate the adoption of ESTs by the shipowners in the first place but instead make the businesses order ships with a reduced design speed (a popular operational measure). New research also shows that shipowners prefer operational measures to technical retrofit measures, and the reluctance of shipowners to adopt energy efficiency technologies for ship retrofitting hinders energy efficiency improvement and green transition in the shipping industry (Kaya & Erginer, 2021). This study aims to contribute to the solutions by answering the main research question:

What drives shipowners' decision to adopt energy-saving technologies (ESTs) for ship retrofitting?

This is a big question and can be explored in different research areas. This research will sharpen the focus by answering two sub-questions.

The first sub-question focuses on shipowners' perspectives. As shipowners directly purchase ESTs instead of producing technologies themselves, they are customers and users of the technologies instead of producers. Understanding users' (shipowners in this context) perspective is key to improving technology acceptance. It is significant to consider users' perspectives for facilitating both technological design and implementation processes (Pakravan & MacCarty, 2020), especially in the face of the bottleneck of the low adoption rate of technical retrofitting measures in shipping. The first sub-question is:

(1) What are the key driving factors for retrofitting ships with ESTs from shipowners' perspective?

The second sub-question focuses on the piece of ship conditions. Ship conditions like ship age and ship size could be crucial to shipowners' decision to adopt energy efficiency measures for existing ships, which is an under-explored area (Kaya & Erginer, 2021). The second sub-question is:

(2) What are the key ship conditions for shipowners to adopt ESTs for ship retrofitting?

By finding the answers to the sub-questions, this research explains the drivers of adopting energy-saving technologies (ESTs) for ship retrofitting from shipowners' perspective. The study can be used to understand shipowners' behavior concerning ESTs and the best ways to promote green technologies to shipowners. It is especially relevant to green technology producers and policymakers who intend to accelerate green transformation in the global maritime sector.

1.3 Scope of the Thesis

This section aims to clarify the scope of the thesis and the central concepts in the study.

First, this thesis only focuses on technical retrofitting measures for existing ships, so new-built ships are not in the discussion of the study. **Ship energy efficiency measures** as an essential concept in this thesis are summarized below in Figure 1. The measures can be categorized into actions for new shipbuilding and standards for existing vessels (Wärtsilä, 2008), including operational measures, technical retrofit measures, and overall management system enhancement (IMO, 2019a). Measures for new shipbuilding include the building of eco-ships. Environmentally friendly ships, known internationally as eco-ships, are ships with the aim of reducing carbon dioxide emissions (Huang et al., 2017). Operational measures include ship speed reduction/optimization, hull cleaning, propeller surface polishing, weather routing, and others (Wärtsilä, 2008). Technical retrofit measures include implementing energy-saving technologies (ESTs) in existing ships. Finally, efforts on ship management systems aim to enhance overall management performance (IMO, 2019a).

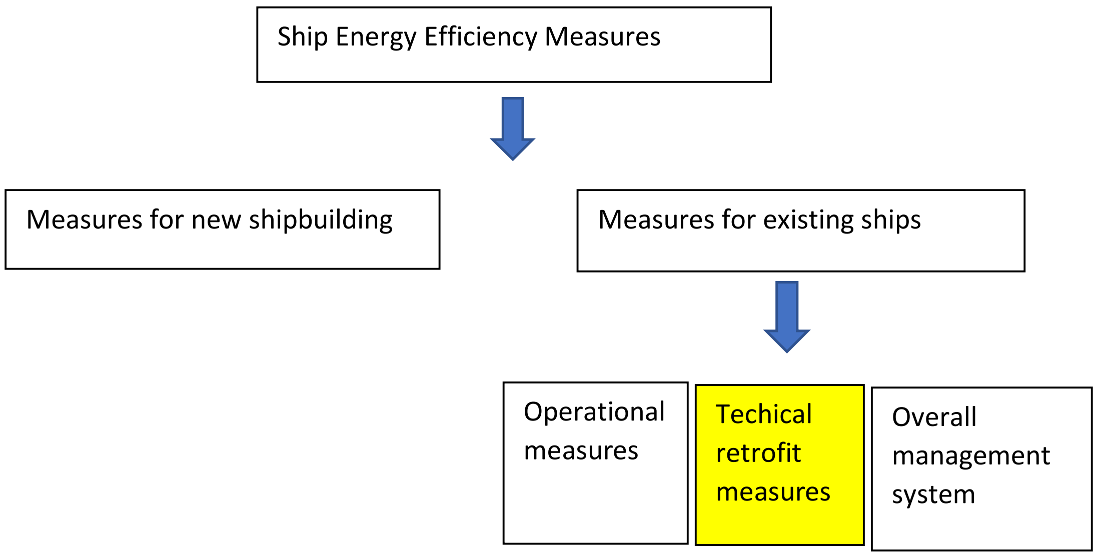

Figure 1: Ship energy efficiency measures. Source: own elaboration based on Wärtsilä (2008) & IMO (2019a)

Second, the technologies covered in this study refer to five groups of ship **energy-saving technologies (ESTs**) designed to improve ship energy efficiency, with key examples summarized in Table 1.1. Other retrofitting technologies (e.g., scrubber) that are not designed for energy efficiency improvement are not in the scope of discussion. According to Clarksons Research (2020), there are five main groups of energy-saving technologies: propeller, hull, engine room, wind, and solar, and they can improve energy efficiency to various extents and thus facilitate the green transition process of the shipping industry. There are around 4000 vessels that have adopted ESTs in the world (Clarksons Research, 2020). However, given the total number of world vessels of around 55000 (Statista, 2021), the adoption rate is deficient.

Table 1-1 Ship energy-saving technologies (ESTs). Source: Clarksons Research(2020)

Groups	Key Technologies	Example Projects	Fuel-saving	Vessels equipped
Propeller	Propeller duct	Becker Mewis Duct	3-8%	>1161
	Rudder Bulb	Rolls-Royce Promas	3-5%	>268
Hull	Bow enhancement	Ulstein X-Bow	4-10%	>252
	Air lubrication system	Silver Stream	5-10%	>71
Engine room	Waste heat recovery system	Calnetix Hydrocurrent	3-8%	>38
	Exhaust gas economiser	Alfa Laval, Wartsila	4-6%	>1515
Wind	Flettner rotors	Norsepower rotor sail	7-10%	>8
	Wind kite	Airseas seawing	Up to 20%	>0
Solar	Solar sail	Eco marine energysail	Up to 20%	>0

Third, **ship retrofitting** in this research refers to "the installation on-board ships of state-of-the-art or innovative components or systems and could in principle be driven by the need to meet new regulatory energy and emission standards or by the shipowner interest to upgrade to higher operational standards"(European Commission, 2015). There is ship retrofitting potential with energy-saving technologies in a considerable percentage of existing world maritime vessels. Thirty-two percent of the ships in the world were built between 2009 and 2013, holding great retrofit potential with the implementation of ESTs (Clarksons Research, 2020).

Mainly targeting existing ships built between 2009 and 2013 and the five groups of technologies, this research aims to investigate the drivers for retrofitting ships with ESTs from the perspective of shipowners.

1.4 Literature Gap

Existing literature on the adoption of energy-saving technologies (ESTs) for retrofitting is mainly concentrated in the context of building retrofit, with critical perspectives summarized below.

Several critical factors that influence the adoption of energy-saving technologies for retrofitting are identified in the literature. Brotman (2017) investigated the specific policy factor of corporate tax policy and found that investment tax credits (ITCs) coupled with lending positively affect new non-residential commercial construction retrofitting. Martiskainen & Kivimaa (2019) investigated several specific drivers that influence successful projects of both existing and new built low-energy housing projects in Brighton, UK, and found that in addition to motivations to improve current housing conditions, knowledge, and available skills of householders and project participants, and both local and national policies, drive energy efficiency retrofitting projects. They also found the crucial impacts of intermediaries in inspiring projects, connecting different actors, and easing learning between projects, especially when lacking effective retrofitting policies. Peel et al. (2020) studied the barriers and enablers to energy efficiency retrofitting in social housing in London. They categorized seven general factors: financial matters, government policy and regulation, technical, IT, quality of craft, and social factors (including disruption to residents and awareness of the energy efficiency agenda).

However, the factors identified in the literature are primarily found in the construction industry context and need to be further examined and explored in the maritime sector, which is a research gap to be further filled in. Therefore, based on existing studies, this research will look further into the drivers of the adoption of ESTs for retrofitting and contribute to filling the research gap by focusing on the context of the global shipping industry.

1.5 Outline of the Thesis

Chapter 1 introduces the background of the urgent need for emission reduction and energy efficiency improvement in the shipping industry and the bottleneck of the low adoption rate of technical retrofit measures by shipowners. Subsequentially, the main research question, "What drives shipowners' decision to adopt ESTs for ship retrofitting?" is proposed. Next, the scope of the thesis and key concepts in the study are defined and clarified. Finally, critical perspectives in the existing literature on the drivers of the adoption of ESTs for retrofitting are summarized, and the literature gap is identified.

Chapter 2 discusses the context of the global shipping industry. A literature review on decision factors of the adoption of ESTs for retrofitting and on the characteristics of the shipping industry is conducted, giving a deep understanding of ESTs retrofitting and the shipping industry.

Chapter 3 discusses the theoretical framework of the thesis. First, relevant decision theories are reviewed. Then, the selected framework of the Theory of Planned Behavior is elaborated. Subsequentially, six hypotheses of the study are proposed based on the context of the shipping industry and the framework of the theory of planned behavior.

Chapter 4 presents the methodology of the research. First, the research philosophy of the study is clarified. Then, research design, including survey design and sampling procedures, is introduced. Next, data collection procedures are presented. Finally, validity and reliability, as well as ethical considerations and methodological limitations, are discussed.

Chapter 5 displays the empirical findings. Results from the survey and the database are presented. Findings are organized based on the theoretical framework of the theory of planned behavior and provide answers to the two sub-research questions.

Chapter 6 further analyses, explains the meaning and identifies the significance of the findings compared to existing studies. The implications and practical recommendations for businesses and policymakers are also discussed.

Chapter 7 summarizes the research findings and draws a conclusion. Finally, the contribution and limitations of the study are discussed, and further research topics are proposed.

Chapter II: The Global Shipping Industry

This chapter investigates the characteristics of the global shipping industry intending to give a deep understanding of the context of the study. First, the concept of shipowner and decision factors within ESTs retrofitting are reviewed. Second, ship energy-saving technologies and key relevant policies in the international maritime sector are discussed. Finally, a short summary of the chapter is presented.

2.1 Shipowners and Decision Factors

This section aims to present the context of the study by reviewing the literature on shipowners and decision factors of ESTs retrofitting. It first introduces the concept of shipowners and charter parties and then summarizes decision factors found within the literature on green retrofit.

2.1.1 Shipowners and Charters

A **shipowner** is the owner of commercial ships who equips and exploits the ships, and a **charterer** is someone renting a vessel for a specified period from the owner and then trading it to transport cargoes at a profit over the hire rate (BV, 2015). **A charter party** specifies the charter price, duration, and terms between the shipowner and charterer based on the type of ship and the type of charter (BV, 2015). In a charter arrangement, the shipowner determines the vessel's specifications and energy efficiency measures, but those benefits are not necessarily theirs (BV, 2015).

Two main types of the charter can be distinguished, **time charter** and **voyage charter/spot charter**. A time charter is chartering "for an extended period including multiple voyages"(McKinsey Energy Insights, 2021). The charterer determines where to go and which ports to visit in the time charter. As part of the charter contract, the charterer pays the vessel's owner a daily hire fee, fuel, port charges, and commissions. There are too few opportunities for charterers to share their investment, which results in split incentives: shipowners may invest capital upfront for energy-efficient technology but do not recoup the savings from fuel savings when they rent the ships out, as this goes to the charterers (Adland et al., 2017). Short-term time charters are particularly susceptible to this issue(BV, 2015).

In contrast, a voyage charter or a spot charter is a one-off chartering for a single voyage, and costs associated with the port, fuel, and crew remain the shipowner's responsibility (McKinsey

Energy Insights, 2021). Compared to the time charter, it is indicated that in the voyage charter, shipowners have more financial incentives to make investment decisions of retrofitting ships with energy-saving technologies (BV, 2015).

2.1.2 Decision Factors of ESTs Retrofitting

Based on a literature review on green retrofit, two commonly mentioned driving factors for the adoption of energy efficiency technologies appear, first, economic and financial matters, and second, information and knowledge.

2.1.2.1 Economic and Financial Matters

Economic and financial matters are essential, according to the literature. These mainly include investment costs, maintenance costs, operational costs, payback periods, and economic risks. Investment cost and payback period are considered significant decision factors in adopting energy efficiency measures in existing ships (Kaya & Erginer, 2021). Likewise, in the field of residential housing retrofitting, it is found that the three most essential decision-making factors are payback period, life-cycle cost, funding mechanism, and the three least considered factors are CO2 emissions, educational programs, and demand pressures, with no significant disagreement between public and private institutions or between executives and non-executive (Medal et al., 2020). This is further supported by Peel et al. (2020), who identify financial matters as crucial decision factors on energy efficiency retrofitting in social housing in London. Similarly, it is found that investment tax credits (ITCs) coupled with lending can increase house owners' investment in retrofitting new non-residential commercial construction (Brotman, 2017). Moreover, funding and economic risks are critical factors that drive or hinder ship energy efficiency projects with energy efficiency technologies based on Danish demonstration projects (Mosgaard & Kerndrup, 2016).

2.1.2.2 Information and Knowledge

Literature shows that information and knowledge play a crucial role in successfully implementing retrofitting with ESTs.

In the absence of explicit cash subsidies, can information itself increase investment in innovative technologies? Morgenstern & Al-Jurf (1999) found that information programs contribute significantly to the diffusion of high-efficiency lighting in commercial office buildings. They also found that retrofits are more likely to be encouraged by this program for people who have already purchased advanced lighting technologies than first-time buyers. Hermann et al. (2016) emphasized the critical role of intermediaries in the diffusion of green technologies in ship retrofitting, and one of their essential functions is increasing the scanning of information. Martiskainen & Kivimaa (2019) explored the role of knowledge as a driver for low-energy housing projects based on case studies from the United Kingdom. They found that the householders' knowledge is an essential driver for the success of energy efficiency projects, both retrofitting and constructing new buildings. Kaya & Erginer (2021) also identified knowledge and experience at a business level as an essential decision factor for shipowners to make energy-saving investments.

2.2 Energy Saving Technologies (ESTs)

In this section, an overview of ship energy-saving technologies is presented. Then, key relevant policies regarding energy efficiency in the maritime sector are identified and elaborated. This section provides a further understanding of the context of the global shipping industry.

2.2.1 Overview of Ship Energy Saving Technologies (ESTs)

An overview of all the energy-saving technologies (ESTs) is summarized based on Clarkson's database, shown in Table 2.1.

Table 2-1 An overview of all the ESTs. Source: own elaboration based on Clarkson's database

Propeller	Hull	Engine room	Wind	Solar
(1)Stator Fin-Pre Swirl (2)Stator Fin-Post Swirl (3)PBCF-Propeller Boss Cap Fin (4)Propeller Duct (5)Rudder Bulb (6)Rudder Fin (7) Hull Vane - Hull Vane (8) Twin Fin - Caterpillar (9) Gate Rudder	(1) Air Lubrication System (2) Bow Enhancement (3) Hull Fin (4) Hull Skating System (5) Bow Foil, Retractable	(1) Exhaust Gas Economiser (2) Waste Heat Recovery System (WHRS)	(1) Wind, Flettner Rotor (2) Wind, Rigid Sail (3) Wind, Kite (4) Wind, Turbosail	(1) Solar, Panel

According to Clarkson's database on ship energy-saving technologies (ESTs), there are five groups of ESTs: Propeller, Hull, Engine Room, Wind, and Solar. Among the five groups of ESTs, the first three groups have a considerable amount of installation, while the wind and solar groups have very few. For considerable energy efficiency improvement, it is also crucial to combine the above ESTs with a derating of the main engine (DNV, 2021).

2.2.2 Key Policies

IMO has developed a Greenhouse Gas Strategy to 2050, aiming to reduce CO2 intensity by 40% over the next decade by 2030 and a total reduction of 50% by 2050 (70% intensity). IMO approved the strategy in 2018. Emission reduction rates refer to the 2008 baseline (IMO, 2019c).

IMO adopts three key energy efficiency regulations on existing ships to reduce emissions: **EEXI** – Energy Efficiency Existing Ship Index, Carbon Intensity indicator **(CII),** and the enhanced Ship Energy Efficiency Management Plan **(SEEMP).** EEXI is a technical measure that only considers the ship's design and is comparable to EEDI for new buildings. At the same time, CII is a corresponding operational measure that considers actual consumption and the distance traveled by each boat, and the enhanced Ship Energy Efficiency Management Plan (SEEMP) targets the overall management system (IMO, 2021).

Regarding ship retrofitting with energy-saving technologies, the most directly relevant and essential regulation is EEXI—Energy Efficiency Existing Ship Index, as it addresses the technical aspects of emission reduction.

2.2.2.1 EEXI – Energy Efficiency Existing Ship Index

The IMO adopted amendments to MARPOL Annex VI at MEPC 76 in June 2021, which will lead to the introduction of an energy efficiency design Index for existing ships--EEXI. The requirements will take effect in January 2023 for all vessels over 400 GT (IMO, 2021).

EEXI requires an EEXI Technical File for most ship types except for those built according to Energy Efficiency Design Index (EEDI) Phase 2 and Phase 3 requirements in the past. The EEXI Technical File calculates the attained energy efficiency index, which must be below a required energy efficiency index. For class approval, the EEXI Technical File must be presented within 2023 and be carried onboard after that (IMO, 2021).

The regulation of EEXI means that shipowners will have to take measures on ships that do not conform to the energy efficiency standards and get the required EEXI Technical File ready before 2023. Failed compliance may lead to fines and affect ships' regular operation (e.g., ship detain) (DNV, 2021). It can be predicted that shipowners will need to invest in technical retrofit measures as EEXI comes into force in 2023, even if they are not economically feasible (Kaya & Erginer, 2021).

2.3 Summary of Chapter II

This chapter presents and gives a deep understanding of the context of the global shipping industry, first by reviewing existing literature on shipowners and decision factors for green retrofit, and second by reviewing ESTs and key energy efficiency policies in the international maritime sector. This chapter identifies **economic and financial matters**, and **knowledge and information** as two key factors affecting shipowners' decision to retrofit ships with ESTs. Furthermore, this chapter identifies the **Energy Efficiency Existing Ship Index (EEXI)** as the critical international regulation for shipowners' decision to retrofit ships with ESTs.

Chapter III: Theoretical Framework

This chapter aims to lay down the theoretical foundation of the study. First, theories and decision models on technology acceptance and pro-environmental behavior are reviewed. Then, the selected theoretical framework for this research—the Theory of Planned Behavior, is justified and elaborated. Subsequentially, six hypotheses of the study based on the theoretical framework and tailored to the context of the shipping industry are proposed.

3.1 Review of Decision Models

As shipowners' adoption of ship energy-saving technologies belongs to technology acceptance and is also a pro-environmental behavior, decision models in both fields are reviewed.

There are eight critical models in the literature on technology acceptance: the theory of reasoned action, the theory of planned behavior, the technology acceptance model, the motivational model, the model combining the technology acceptance model, and the model of PC utilization, the innovation diffusion theory, and the social cognitive theory (Venkatesh et al., 2003). Based on these eight theories, Venkatesh et al. (2003) also developed the Unified Theory of Acceptance and Use of Technology (UTAUT).

There are five most common decision models on pro-environmental behaviors: norm activation model, value-belief-norm theory, goal framing theory, the ipsative theory of behavior, and comprehensive action determination model (Klöckner, 2015).

In Figure 2 below, theories on technology acceptance are grouped in the left circle, and theories on pro-environmental behaviors are grouped in the right circle. There is one single theory in the overlapped area: the theory of planned behavior. Therefore, it suits the context of the study from both aspects of technology acceptance and pro-environmental behaviors. Further examination shows that the theory is also well established and examined, with wide application in various fields (Ajzen, 2020).

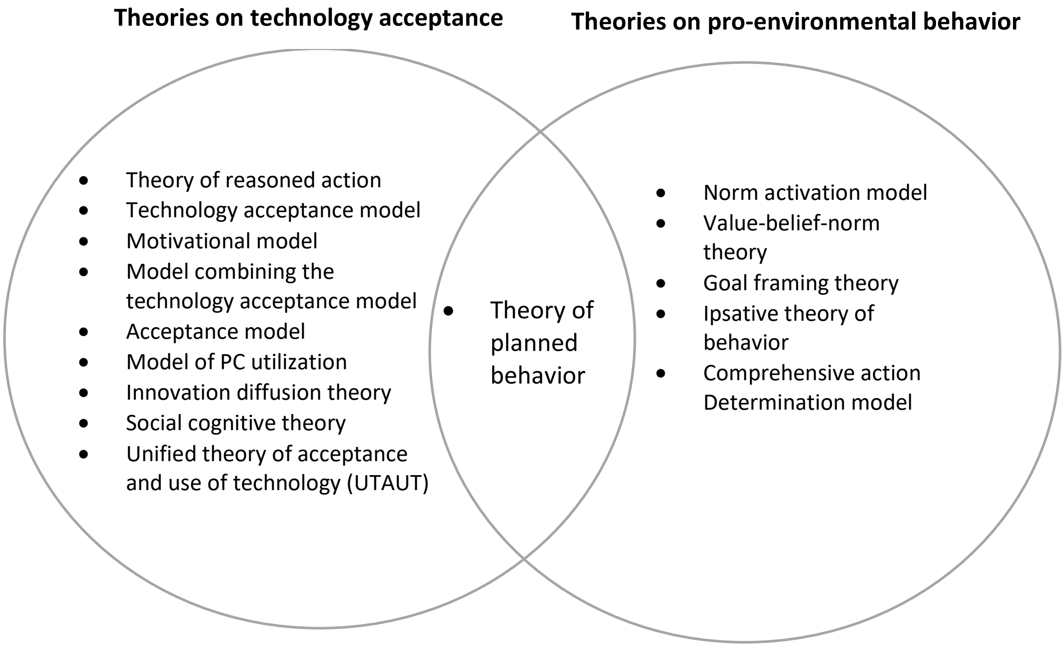

Figure 2: Review of decision models. Source: own elaboration

3.2 Theory of Planned Behaviour

The theory of planned behavior is selected from the reviewed decision models as the theoretical framework for this thesis. This section introduces the theory and further explains why it is suitable for the study.

3.2.1 Overview of Theory of Planned Behavior

Down to the root, the theory of planned behavior was initially developed from the Theory of Reasoned Action (TRA). Down from social psychology, TRA is one of the most fundamental and influential human behavior theories (Venkatesh et al., 2003). Various kinds of behaviors can be predicted using TRA (Sheppard et al., 1988). According to Davis (1989), using TRA in the context of acceptance of technology provided results broadly in line with those from studies employing TRA in other contexts. TRA has two constructs: attitude towards behavior and subjective norm, and they both have a cause-effect relationship with behavioral intention (Ajzen, 1985).

Theory of Planned Behavior (TPB) extended TRA by adding the construct of perceived behavioral control. TPB theorizes perceived behavioral control as another factor affecting intentions and behavior. Ajzen (1991) reviewed studies that successfully applied to understanding individual acceptance and usage of numerous technology (Taylor & Todd, 1995) and presented TPB. The model of TPB is elaborated in Figure 3:

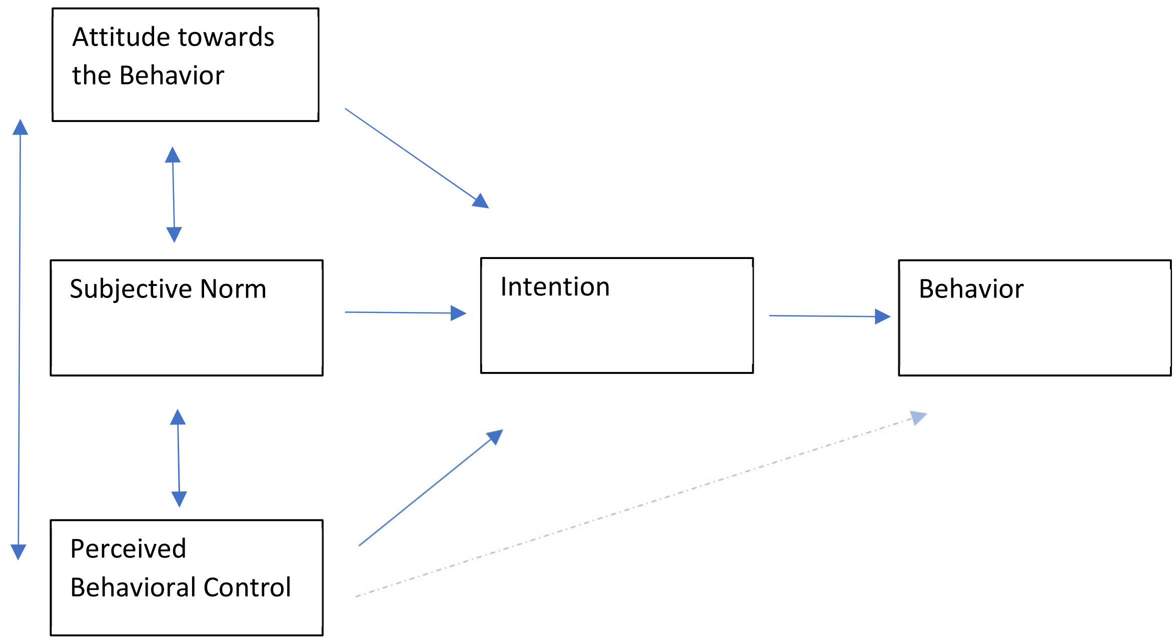

Figure 3: Theory of Planned Behavior. Source: Ajzen (1991)

3.2.2 Justification of the Theory

This research adopts the theory of planned behavior for three main reasons.

First, as mentioned before, it is the single theory in both fields of technology acceptance and pro-environmental behaviors based on the review of a wide range of theories and decision models. As shipowners' adoption of energy-saving technologies (ESTs) for ship retrofitting is technology acceptance with pro-environmental effects, it fits the context of the study best.

Second, it is a well-established theory with wide application, which means it is well-examined in previous studies, with demonstrated effectiveness and credibility. The simplicity of the theory and the ability to apply it to a wide range of behavioral domains makes it one of the most popular and fundamental theories on technology acceptance (Klöckner, 2015). Moreover, empirical evidence supports the theory broadly (Ajzen, 1991). Multiple meta-analyses have demonstrated the effectiveness of the Theory of Planned Behavior in predicting intentions and behaviors (Conner & Armitage, 1998).

Third, there is also a well-developed methodology, especially the survey method, along with the well-established status of the theory, and the adoption of the theory can increase the feasibility of carrying out this study regarding research design and methodology in general.

Given the above reasons, the theory of planned behavior is selected as the most appropriate theoretical framework for this study.

3.2.3 Core Constructs of Theory of Planned Behavior

There are three core constructs in the Theory of Planned Behavior (TPB): attitudes toward the behavior (ATT), subjective norm (SN), and perceived behavioral control (PBC). The definitions in the literature are elaborated in Table 3.1:

Table 3-1 Core constructs of the theory of planned behavior. Source: Fishbein and Ajzen (1975), Ajzen (1991), Ajzen(2020)

Core constructs	Definitions	Items for measurements
Attitudes toward the behavior (ATT)	"An individual's positive or negative feelings (evaluative effect) about performing the target behavior" (Fishbein & Ajzen, 1975: p. 216)	Behavioral outcomes (Ajzen, 2020)
Subjective norm (SN)	"The person's perception that most people who are important to him think he should or should not perform the behavior in question" (Fishbein and Ajzen, 1975: p. 302)	Normative referents (Ajzen, 2020)
Perceived behavioral control (PBC)	"The perceived ease or difficulty of performing the behavior" (Ajzen, 1991: p. 188)	Control factors (Ajzen, 2020)

The three core constructs, i.e., attitudes toward the behavior, subjective norm, and perceived behavioral control, can predict intentions to perform behaviors of various kinds with high accuracy (Ajzen, 1991). Furthermore, these intentions, together with perceptions of behavioral control, account for considerable variance in actual behavior (Ajzen, 1991), which means the three constructs of the theory of planned behavior have considerable predicting power of actual behaviors.

3.2.4 Hypotheses

Six hypotheses are developed based on the three constructs of the theory of planned behavior and tailored to the context of the global shipping industry, as shown in Table 3.2.

Table 3-2 Hypotheses. Source: own elaboration

Constructs	**Items**	**Hypotheses**
Attitude (ATT)	ATT1. Higher Market Competitiveness (behavioral outcome 1)	Hypothesis 1: Higher market competitiveness has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.
	ATT2. Compliance with EEXI (behavioral outcome 2)	Hypothesis 2: Compliance with EEXI has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.
Subjective Norm (SN)	SN1. Governments' advocacy (normative referent 1)	Hypothesis 3: Governments' advocacy has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.
	SN2. Competitors' adoption (normative referent 2)	Hypothesis 4: Competitors' adoption has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.
Perceived Behavioural Control (PBC)	PBC1. Financial resources (control factor 1)	Hypothesis 5: Financial resources have a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.
	PBC2. Knowledge and experience (control factor 2)	Hypothesis 6: Knowledge and experience have a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.

The six items/factors of higher market competitiveness (ATT 1), compliance with EEXI (ATT 2), governments' advocacy (SN 1), competitors' adoption (SN 2), financial resources (PBC 1), knowledge and information (PBC 2) are set at the independent variables (IVs) of the study. Moreover, shipowners' intention to adopt ESTs for ship retrofitting is the dependent variable (DV).

3.3 Summary of Chapter III

In this chapter, relevant decision theories and models are reviewed, and the theory of planned behavior is selected and justified as the framework for this research. Next, the core constructs of the theory are elaborated: **attitude (ATT)**, **subjective norms (SN)** and **perceived behavioral control (PBC)**. Finally, based on the three constructs, variables in the study along with six hypotheses are clarified:

H1: Higher market competitiveness (ATT 1) has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.

H2: Compliance with EEXI (ATT2) has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.

H3: Governments' advocacy (SN 1) has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.

H4: Competitors' adoption (SN 2) has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.

H5: Financial resources (PBC 1) have a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.

H6: Knowledge and information (PBC 2) have a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.

Chapter IV: Methodology

This chapter aims to lay down the methodological foundation of the study. It commences by briefly introducing the research philosophy of the study. Next, the research design, as well as survey design and sampling choices, are elaborated. Then, data collection procedures are presented. Finally, validity and reliability, following ethical considerations and methodological limitations, are discussed.

4.1 Research Philosophy

Research philosophy can help clarify research design and is thus discussed first. This section presents the study's ontology, epistemology, and research approaches.

Ontology is defined as a philosophical assumption on the nature of reality, with four different positions: realism, internal realism, relativism, and nominalism (Easterby-Smith et al., 2012). This research takes the position of internal realism and assumes that truth exists though obscure, and facts can be accessed though not directly (Easterby-Smith et al., 2012).

Epistemology is the best way of enquiring into the nature of the physical and social worlds, with common positions such as positivism and constructionism (Easterby-Smith et al., 2012). In line with the ontology of internal realism, this research takes the epistemological position of positivism. Positivism is considered one of the appropriate ways to investigate human and social behavior (Easterby-Smith et al., 2012), which suits the purpose of studying shipowners' behavior in this research.

Subsequentially, this study adopts mainly a quantitative method and a deductive approach. A deductive approach is a strategy when the researcher conducts the research based on going from a theoretical perspective toward the empirical findings (Easterby-Smith et al., 2012). The researcher uses the basis of what is already known about a specific field and, using theoretical considerations in relation to that domain, creates hypotheses that later must be subjected to empirical examination (Bryman and Bell, 2007). This study starts from the theory of planned behavior, develops six hypotheses which have been presented at the end of chapter three, and intends to test the hypotheses using empirical data in a later chapter.

4.2 Research Design

Ideally, a research design should explain what data is to be collected, where and how to manage the data, and how the research questions are to be answered by analyzing the data (Easterby-Smith, 2012).

To answer the first sub-question, “what are the key driving factors for retrofitting ships with ESTs from the perspective of shipowners?” the author surveys shipowners that have adopted ESTs globally. Then, based on the theoretical framework of the Theory of Planned Behavior, data measuring the variables based on the three constructs of the theory, i.e., shipowners' attitude towards retrofitting ships with ESTs, subjective norms, and shipowners' perceived behavioral control towards retrofitting ships with ESTs, is collected. The data is collected through the online questionnaire platform "Nettskjema.".

To answer the second question, "What are key ship conditions for shipowners to adopt ESTs for ship retrofitting?" the author analyzes a statistical database. The data includes over 4000 profiles of all the registered ships with ESTs adoption globally and is collected from the database of the World Fleet Register.

4.2.1 Survey Design

Following the instruction of the Theory of Planned Behavior (Ajzen, 2020), the survey design is shown in the following steps:

Step 1: Defining the Behavior: adopt ESTs for ship retrofitting

Before getting started, it is necessary to clearly define the behavior of interest, including its target, action, context, and time (Ajzen, 2020). In this research, the target is energy-saving technologies (ESTs). The action is to adopt. The context is ship retrofitting. Moreover, the time frame is defined as before 2023 when designing survey questions that measure future intention and is left unspecified when creating survey questions that aim to find out the factors that drive ESTs adoption both in the past and future.

The theory of planned behavior can be used to measure a group of behaviors apart from a single specific behavior (Ajzen, 2020). As there are diverse options for ESTs, the behavior of "adopt ESTs for ship retrofitting" is defined as a group of behaviors with different ESTs options.

Step 2: Specifying the Research Population: all the shipowners that have installed ESTs

The research population is specified as all the shipowners that have installed ESTs globally, approximately 900 shipowners for over 4000 ships. Because of the shipowners' experience and knowledge with ESTs, they are assumed to provide the most insights into the study.

Steps 3: Eliciting Salient beliefs and Constructing Sets of Modal Salient Beliefs

Salient beliefs refer to behavioral outcomes, normative referents, and control factors and are crucial in determining survey items (Ajzen, 1991). For eliciting salient beliefs, Ajzen (2020) suggests that a sample of individuals representative of the population should be surveyed first individually using free-response questions, and a content analysis typically follows. For practicality and feasibility, this study first identifies salient beliefs and items through a review of existing literature, then through free-response questions in the survey.

Six salient model beliefs are constructed first: higher market competitiveness (ATT 1, behavioral outcome 1), compliance with EEXI (ATT2, behavioral outcome 2), governments' advocacy (SN 1, normative referent 1), competitors' adoption (SN 2, normative referent 2), financial resources (PBC 1, control factor 1), knowledge and information (PBC 2, control factor 2).

Step 4: A Pilot Study

The pilot questionnaire is designed following the standard TPB survey instructions by Ajzen (2006). It is sent to five shipowners and three project managers in the EU WASP project. Based on the valuable feedback and test results received in the pilot study, the questionnaire is further revised before the final data collection procedure. For example, questions with low clarity or showing inconsistency are either dropped or rephrased. The pilot study contributes to improved credibility and reality of the final questionnaire.

4.2.2 Sampling Choice

As specified in the survey design, the research population is all the shipowners that have installed ESTs, around 900 in total in the World Fleet Register. Therefore, the sample, a segment of the population (Easterby-Smith et al., 2012), should be shipowners selected from the about 900 registered shipowners that have installed ESTs.

This research chooses to send the survey to the whole population instead of selecting a segment of it in advance for the following reasons. First, the population is clearly defined, with the whole list of shipowners available on the World Fleet Register. Second, the population is not too big; only around 900 shipowners have adopted ESTs globally. Therefore, it is feasible to send the survey to the entire population, and this eliminates potential researcher bias in the selection procedure.

Essential lessons are learned in the sampling choice. First, the attempt to survey the entire population turns out to be highly time and energy-consuming, especially the process of trying to find personal contact from all the companies. Second, potential sample bias should be aware of due to the possible significant differences between the survey respondents and non-respondents. Though the author can decide whom to survey, who responds to the survey is beyond control in practice. Nevertheless, this is indeed another reason for sending the survey to the entire population because more recipients mean more possible responses as the whole population itself is small.

According to Easterby-Smith et al. (2012), probability sampling has higher credibility than non-probability sampling. Thus, the author intends to achieve probability sampling in this study. Ideally, the survey respondents should be completely random and represent a whole range of different opinions in the population. The author has contacted managers in companies of various locations, sizes, and types to make the respondents as random as possible. In addition, the author has made the survey questions as easy to answer as possible and completely anonymous, so it does not require much motivation to complete and capture a variety of respondents.

4.3 Data Collection

The data collection mainly refers to collecting responses for the final survey, which takes one and a half months and turns out to be the most challenging part of the thesis.

4.3.1 Final Survey

The author sent the final survey to all the registered shipowners globally that have installed ESTs, being around 900 in total, mainly through three channels.

First, the author collected and organized the company email addresses from the database of the World Fleet Register. Afterward, the author crafted and sent two primary emails and three reminders to the company emails of all the shipowners. However, the response rate was meager; only around 15 responses were collected in the first two weeks.

Second, the author manually collected managers' email addresses from the websites of around 900 shipping companies meanwhile, which turned out to be extremely time-consuming but also practical, with one month taken. However, only some of the shipping companies, especially small ones, listed their managers' email addresses on their companies' websites, which often means only a few emails can be found after a whole day of browsing numerous companies' websites and searching for contacts.

Third, to reach the big companies like MSC, the author searched for managers of the companies through LinkedIn and sent personalized invitations to them in the last two weeks of the data collection phase. This turned out to be more than time-consuming because most managers were out of the author's connection. It took a long time and needed several reminders before the managers accepted the invitation and answered the survey.

Despite the efforts put into the data collection, only 42 valid responses (excluding test responses and incomplete answers) have been collected in the limited time span of one and half months. Nevertheless, it almost triples the initial 15 responses. The final questionnaire with data is displayed in Appendix 1. The data are mainly numeric on a scale from 1 to 7. Later on, regression analysis is conducted after a thorough check of the data, elaborated in the next chapter.

4.3.2 Database of World Fleet Register

Facilitated by CHNL, more than 4000 profiles of ships that have installed ESTs in the world are collected from the database of the World Fleet Register. Each ship profiles contain ship name, size, age, power type, energy-saving technologies installed, flag state, shipowner, shipbuilder, and ship operator. Statistical analysis software, including Excel and SPSS, is used to generate results, mainly in the form of visual tables and figures.

4.4 Validity

Validity is to which extent a study accurately measures what it is supposed to measure (Easterby-Smith et al., 2012).

There are two types of validity: internal and external (Easterby-Smith et al., 2012). A study's internal validity, or credibility, indicates whether its results are accurate and if it has identified the correct cause. Internal validity is dealt with in data analysis as part of the research process. It can be enhanced by pattern matching, explanation building, and addressing competing explanations. A study's external validity, or transferability, looks at whether its findings can be generalized. The validity of external research can be enhanced because of robust research designs, using established theories, and description contexts (Easterby-Smith et al., 2012).

Regarding the survey design, it strictly follows the guideline of the Theory of Planned Behavior, which is an established and well-examined method that accurately measures the three constructs of TPB: in this research, they are attitude toward retrofitting ships with ESTs, subjective norms, and perceived behavior control towards retrofitting ships with ESTs. Therefore, given the well-examined and universal applicability of the survey method to the theory of planned behavior and the authors' following it closely, both internal validity and external validity of the survey are deemed sufficient.

4.5 Reliability

According to Easterby-Smith et al. (2012), reliability often refers to the consistency of a composite variable formed by combining scores on multiple items in a survey study, and it can be calculated using Cronbach's alpha.

In the survey design, each variable is measured by at least two questions to examine reliability better. In addition, Cronbach's alpha is used to examine the internal consistency of the survey. Questions in the pilot questionnaire that shows low internal consistency or lack of clarity are either removed or improvised in the final questionnaire, thus improving the consistency of measurement and reliability in the final study.

4.6 Ethical Considerations

There are four primary ethical considerations in conducting research: harm to participants, deficient informed consent, invasion of privacy, and involved deception (Bryman & Bell, 2007).

No personal data is collected in this research, so participants' names, titles, company names, locations, email addresses, and other information that can potentially identify the participants are not collected. The survey is distributed through the Norwegian data collection platform "Nettskjema," where no IP address is collected. This keeps the questionnaire completely anonymous and follows the principles of no harm to participants and no invasion of privacy.

Furthermore, the participants are fully informed about the authentic research aim, data protection terms, and their rights before taking the survey. Only when the participants read the informed consent and agree to participate can the survey page proceed (the informant consent and online survey can be accessed at https://nettskjema.no/a/255600). Moreover, they can also quit at any moment in answering the questionnaire as the participation is entirely voluntary. This follows the principles of no involved deception and deficiency of informed consent.

4.7 Methodological Limitations

As Ajzen (2020) stated, the actual behavior is determined by both users' intentions and actual behavior control. In other words, even if the user has high motivation towards a behavior, the behavior would not happen in the end if there were a lack of facilitating conditions and actual control over the desired behavior. However, as Ajzen (2020) mentioned, actual behavior control is much harder to measure compared to perceived behavior control, and perceived behavior control can, to some extent, substitute actual behavior control.

This research only digs into the motivation piece, i.e., what motivates shipowners to retrofit ships with ESTs, by measuring the three constructs of motivation, i.e., attitude towards retrofitting ships with ESTs, subjective norms, and perceived behavior control towards retrofitting ships with ESTs. Though motivation is a vital component that leads to shipowners' behavior of retrofitting ships with ESTs, we cannot ignore the role of actual behavioral control, which may be seen as a hard-to-measure factor that drives shipowners' actual behavior. The unforeseen barriers and contingencies like unexpected hostile markets, military conflicts in ship operating areas, etc., can all affect shipowners' actual control of retrofitting ships with ESTs in the future. However, it is hard to measure unforeseen barriers and contingencies that influence actual behavior control though they are crucial in accurately explaining and predicting shipowners' behavior toward adopting ESTs for ship retrofitting. In this research, shipowners' perceived behavioral control of retrofitting ships with ESTs is measured, representing actual behavior control, but to a limited extent.

Chapter V: Results

This chapter displays the empirical findings and answers the research questions in three sections. 5.1 shows the survey results and answers the first sub-question: what are the key driving factors for retrofitting ships with ESTs from shipowners' perspective? 5.2 displays the database results and answers the second sub-question: what are key ship conditions for shipowners' adoption of ESTs for retrofitting? 5.3 wraps up the whole chapter with a figure summarizing the empirical findings of the thesis.

5.1 Survey Results

The survey results aim to answer the first research question: ***What are the key driving factors for retrofitting ships with ESTs from shipowners' perspective?*** The section commences by presenting the sample demographics to understand the composition and representativeness of the sample. Then, the survey data is checked thoroughly, especially regarding regression assumptions. Next, the relationships between the independent variables and the dependent variable are examined through regression modeling. In addition, the results from open-ended questions are also presented. Finally, the hypotheses testing results and answers to the first sub-question are summarized at the end of the section.

5.1.1 Sample Demographics

The sample demographics are first analyzed because it helps conceptualize the findings correctly and accurately.

Table 5-1 Sample Demographics

	Decision-makers in the company	Past ship retrofitting with ESTs
Yes	66.7% (n=28)	69.0% (n=29)
No	33.3% (n=14)	29.0% (n=13)

Note: N=42

Forty-two valid survey responses were collected, excluding responses in the pilot study and incomplete answers, with a responding rate estimated at 5%. Nearly 70 percent of the responding companies have adopted ESTs for ship retrofitting in the past. Besides, almost 70 percent of the respondents are decision-makers in their company, as shown in Table 5.1. Other demographic information like age, gender, ethnicity, and location of the participants remains completely anonymous because no personal data is collected as agreed in the consent with participants.

5.1.2 Measurement of Variables

Six independent variables or factors mentioned at the end of chapter three are measured: higher market competitiveness (ATT 1), EEXI compliance (ATT 2), governments' advocacy (SN 1), competitors' adoption (SN 2), financial resources (PBC 1), knowledge and experience (PBC 2). In addition, the dependent variable, shipowners' intention to adopt ESTs for ship retrofitting (Intention), is also measured. The value of each factor is measured by multiplying the subjective evaluation of the outcome or experience (e) and the strength of each assessable belief (b) according to Ajzen (2020), i.e., ATT i=ATT I (ei) * ATT i (bi), SN i=SN i (ei) * SN i (bi), PBC i=PBC I (ei) * PBC i (bi). Measurement results of variables are summarized in Table 5.2.

Table 5-2 Measurement of variables

	Min	Max	Mean	Std. Dev
(ATT 1) Higher market competitiveness	**1**	**49**	**8.24**	**10.504**
Q3 (ATT1, e1). My company's adopting ESTs for ship retrofitting will result in higher market competitiveness.	1	7	3.02	1.919
Q4 (ATT1, b1). My company's higher market competitiveness is	1	7	2.12	1.452
(ATT 2) EEXI compliance	**1**	**49**	**5.40**	**7.711**
Q5 (ATT2, e2). Adopting ESTs for ship retrofitting will help my company to comply with EEXI.	1	7	2.57	1.516
Q6 (ATT2, b2). For my company, complying with EEXI is	1	7	1.83	1.267
(SN 1) Governments' advocacy	**1**	**36**	**8.10**	**6.573**
Q7 (SN1, e1). Governments think my company should adopt ESTs for ship retrofitting.	1	7	3.43	1.516
Q8 (SN2, b1). When it comes to adopting ESTs for ship retrofitting, how much does my company want to follow policies?	1	6	2.21	1.048
(SN 2) Competitors' adoption	**1**	**30**	**9.33**	**7.953**
Q9 (SN2, e2). My competitor shipowners have adopted ESTs for ship retrofitting.	1	7	3.60	1.466
Q10 (SN2, b2). When it comes to adopting ESTs for ship retrofitting, how much does my company want to keep up with other shipowners?	1	6	2.33	1.262
(PBC 1) Financial resources	**1**	**20**	**4.76**	**4.113**
Q11 (PBC1, e1). My company expects to have financial resources to retrofit ships with ESTs.	1	5	2.52	1.042
Q12 (PBC1, b1). Having financial resources enables my company to adopt ESTs for ship retrofitting.	1	4	1.69	.841
(PBC 2) Knowledge and experience	**1**	**20**	**4.29**	**4.441**
Q13 (PBC2, e2). My company expects to have knowledge and experience to retrofit ships with ESTs.	1	5	2.02	.975
Q14 (PBC2, b2). Having knowledge and experience enables my company to retrofit ships with ESTs	1	6	1.79	1.025
(Intention) My company intends to adopt ESTs for ship retrofitting before 2023.	**1**	**7**	**3.81**	**1.656**

Note: smaller the number, the stronger the degree of agreement or importance.

5.1.3 Regression Conditions

Before further analysis of the data, the shape of the data and regression assumptions have been checked to ensure the applicability of regression analysis that is typically in use of the application of the theory of planned behavior.

Assumption 1: no outliers.

This assumption means that neither IVs nor DV should have outliers, in other words, no leverage points or influential cases, because regression results tend to be highly influenced by outliers (Tabachnick et al., 2007). This assumption has been checked in this research by looking at standard residual statistics, which should be between -3.29 and 3.29 (George & Mallery, 2019).

When running residual analysis for the first time, the results are shown in Table 5.3. The residual maximum of 3.25 almost exceeds 3.29. To make the data fit better the regression, the author diagnoses one survey response as an outlier and removes it, with the specific information shown in Table 5.4. After removing the outlier, the new residual statistics are shown in Table 5.5. Both the minimum of Std. Residual minimum of -1.793 and the maximum of 2.417 have met the assumption very well.

Table 5-3 Initial residual statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Std. Residual	-1.602	3.250	.000	.924	42

a. Dependent Variable: (Intention) My company intends to adopt ESTs for ship retrofitting before 2023.

Table 5-4 Casewise diagnostics

Case Number	Std. Residual	Intention	Predicted Value	Residual
15	3.250	7	2.83	4.168

a. Dependent Variable: (Intention) My company intends to adopt ESTs for ship retrofitting before 2023.

Table 5-5 Adjusted residual statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Std. Residual	-1.793	2.417	.000	.922	41

a. Dependent Variable: (Intention) My company intends to adopt ESTs for ship retrofitting before 2023.

Assumption 2: normality

This assumption means the data needs to be normally distributed, in other words, symmetrical (Tabachnick et al., 2007). The more symmetrical the data is, the better the data fits the regression. This is checked first by looking at the P-P plot (George & Mallery, 2019). Ideally, the P-P Plot of standardized residual error dots should be on or close to the diagonal line. As shown in Figure 4, the P-P Plot of standardized residual errors of the survey data is mostly close to the diagonal line despite some deviations.

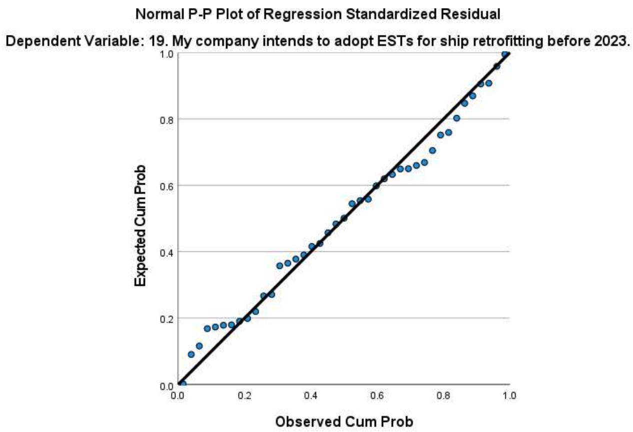

Figure 4: Normality of the data

In addition, the normal curve has also been checked to examine further the symmetry of the data, shown in Figure 5 below. It is primarily symmetrical after removing the outliers mentioned in assumption 1, though not ideal in a bell curve.

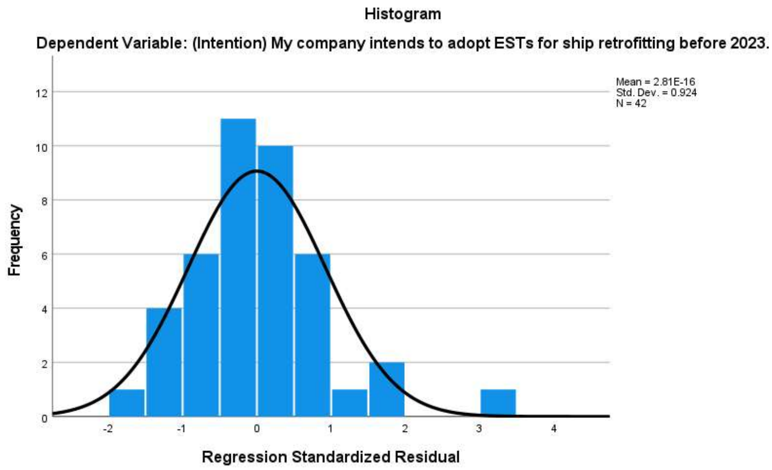

Figure 5: Symmetrical distribution of the data

Assumption 3: homoscedasticity

This assumption means residuals experience constant variance that needs to be independent of the value of x (Tabachnick et al., 2007). This is checked by observing the scatterplot of predicted errors vs. standardized residual errors (George & Mallery, 2019).

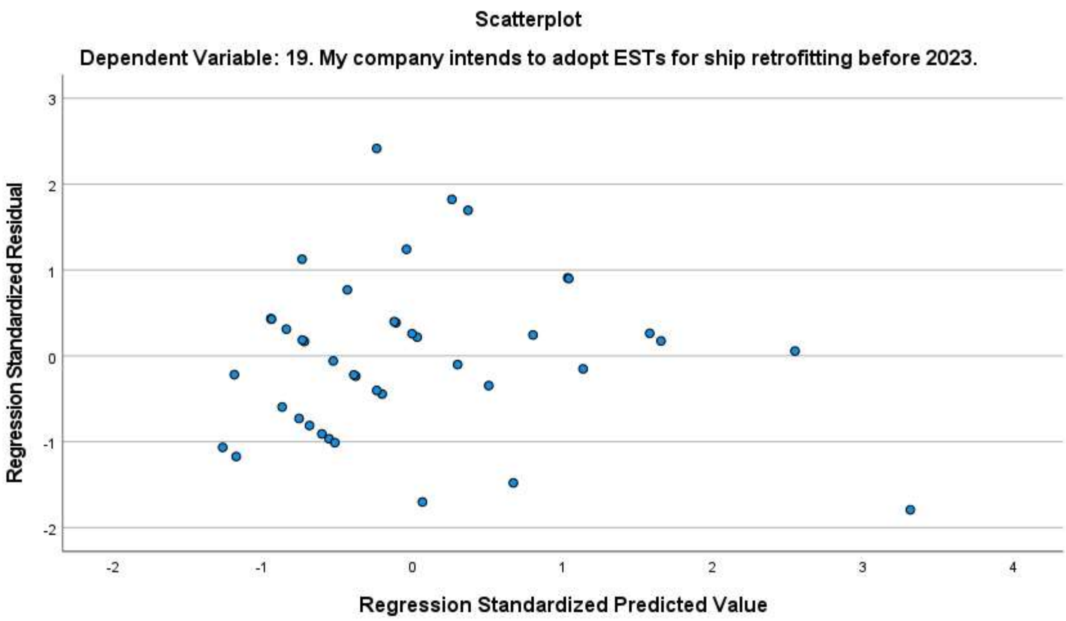

Figure 6: Homoscedasticity of the data

The scatterplot of predicted errors vs. standardized residual errors should be roughly elliptical. As shown in Figure 6, the scatterplot with no outliers is roughly round. However, it is a bit far from perfectly round; this may affect the results and be considered a limitation.

Assumption 4: linearity

This assumption means that the dependent variable (DV) must be numeric at the scale level and go on Y-axis; Independent variables (IVs) must be numeric at the scale level or numeric categorical, going to the X-axis, and according to the independent variables chosen for the model, Y must be a linear function (Tabachnick et al., 2007). In this research, all the data used for measuring the variables from the survey are numeric data at the scale level, with DV and IVs showing a linear distribution.

Assumption 5: independence of observations/ multicollinearity

This assumption is to make sure the predictors or the variables are not too strongly correlated and predict different amounts of variability in the regression model (Tabachnick et al., 2007).

The author checks the assumption by observing the Dubin-Watson statistic, an autocorrelation test ranging from 0 to 4. To meet the assumption, Dubin-Watson should be between 1 to 3 and ideally close to 2 (George & Mallery, 2019). In this study, Dubin-Watson statistics is calculated at 2.400, shown in Table 5.6, so this assumption has been met.

Table 5-6 Dubin-Watson statistics

Model	R	R Square	Adjusted R Square	Durbin-Watson
1	.789[a]	.622	.556	2.400

In addition, collinearity statistics have also been examined by checking the VIF and tolerance statistics. To avoid multicollinearity, the VIF should be less than 10, and the tolerance should be greater than 0.10 (Tabachnick et al., 2007). Each independent variable's VIF and tolerance statistics have been checked in this research, as shown in Table 5.7. The tolerance statistics of all six IVs are all above 0.1, and the VIF is below 10. This means all six IVs in this study are independent of each other, and neither of them needs to be dropped.

Table 5-7 Tolerance and VIF statistics

Model		Collinearity Statistics	
		Tolerance	VIF
1	(Constant)		
	Higher market competitiveness	.493	2.028
	EEXI compliance	.941	1.063
	Governments' advocacy	.650	1.538
	Competitors' adoption	.456	2.195
	Financial resources	.459	2.179
	Knowledge and experience	.425	2.354

5.1.4 Regression Results

After checking the descriptive statistics of the data and the assumptions, the foundation is laid down for regression model building.

First, correlation analysis is conducted to understand the relationship between the six independent variables (ATT1, ATT2, SN1, SN2, PBC1, PBC2) and the dependent variable (Intention), with results shown in Table 5.9. The results show a strong correlation between shipowners' intention to adopt ESTs for ship retrofitting and the five factors of EEXI compliance (ATT 2), governments' advocacy (SN 1), competitors' adoption (SN 2), financial resources (PBC 1), knowledge and experience (PBC 2). In contrast, no strong correlation is shown with the factor of higher market competitiveness (ATT 1). Among the five factors, **EEXI compliance (ATT 2)** shows the **strongest positive correlation** with shipowners' intention of adopting ESTs for ship retrofitting.

Table 5-8 Correlation among variables

	ATT1	ATT2	SN1	SN2	PBC1	PBC2	Intention
ATT1	1						
ATT2	.069	1					
SN1	.269	.223	1				
SN2	.590**	.142	.526**	1			
PBC1	.513**	.110	.325*	.252	1	.	
PBC2	.546**	.152	.375*	.409**	.844**	1	
Intention	.249	**.491****	.483**	.460**	.366*	.386*	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Next, two regression models are established to examine further the causal relationships between the independent and dependent variables. The two models have met the conditions for regression after diagnosing and removing one outlier from the data set. Regression results are shown in Table 5.9 and Table 5.10.

Table 5-9 Regression model 1

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	1.744	.333		5.230	<.001
	(ATT 1) Higher market competitiveness	-.036	.023	-.240	-1.572	.125
	(ATT 2) EEXI compliance	.086	.022	.422	**3.871**	**<.001**
	(SN 1) Governments' advocacy	.033	.032	.135	1.021	.314
	(SN 2) Competitors' adoption	.092	.032	.463	**2.928**	**.006**
	(PBC 1) Financial resources	.166	.081	.428	**2.044**	**.049**
	(PBC 2) Knowledge and experience	-.030	.076	-.083	-.388	.700

a. Dependent Variable: (Intention) My company intends to adopt ESTs for ship retrofitting before 2023.

b. Model 1 summary: **adjusted R square=.552**, **F Change=9.205**

Model 1 includes and examines all six factors of higher market competitiveness (ATT 1), EEXI compliance (ATT 2), governments' advocacy (SN 1), competitors' adoption (SN 2), financial resources (PBC 1), knowledge and experience (PBC 2), as shown in Table 5.9. The value of adjusted R square .552 illustrates that the six factors can explain 55 percent of the measured variance of shipowners' intention. In addition, the value of F change 9.205, which is a high value, indicates that the regression model fits the data, and the independent variables interpret the variance of the intention.

The results of model 1 illustrate that **(ATT 2) EEXI compliance**, **(SN2) competitors' adoption,** and **(PBC 1) financial resources** are the three most important driving factors that motivate shipowners to adopt ESTs for ship retrofitting before 2023, with a p-value all less than 0.05. Again, big t-values and standard coefficients underpin this. In contrast, the other three independent variables, (ATT 1) higher market competitiveness, (SN 1) governments' advocacy, and (PBC 2) knowledge and experience, show no causal relationships with shipowners' intention toward retrofitting ships with ESTs. This is shown by p-value all more than 0.05, underpinned by small t-values and standard coefficients.

Model 2, as shown in Table 5.10, includes only the three most significant factors of (ATT 2) EEXI compliance, (SN2) competitors' adoption, and (PBC 1) financial resources. The value of adjusted R square .533 illustrates that the three factors can explain 53 percent of the measured variance of shipowners' intention. In addition, the value of F change improves to 16.226 from 9.205 in model 1, which is a significant improvement and indicates that model 2 fits much better than model 1.

Table 5-10 Regression model 2

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
2	(Constant)	1.944	.320		6.066	<.001
	(ATT 2) EEXI compliance	.092	.022	**.448**	**4.096**	**<.001**
	(SN 2) Competitors' adoption	.077	.022	.388	3.460	.001
	(PBC 1) Financial resources	.114	.043	.295	2.642	.012

a. Dependent Variable: (Intention) My company intends to adopt ESTs for ship retrofitting before 2023.

b. Model 2 summary: adjust R square=.533, F change=16.226

The results of model 2 further show that **(ATT 2) EEXI compliance** is **the most significant driver** for shipowners to retrofit ships with ESTs, with (SN2) competitors' adoption and (PBC 1) financial resources in the second and third place, with the model visualized in Figure 7.

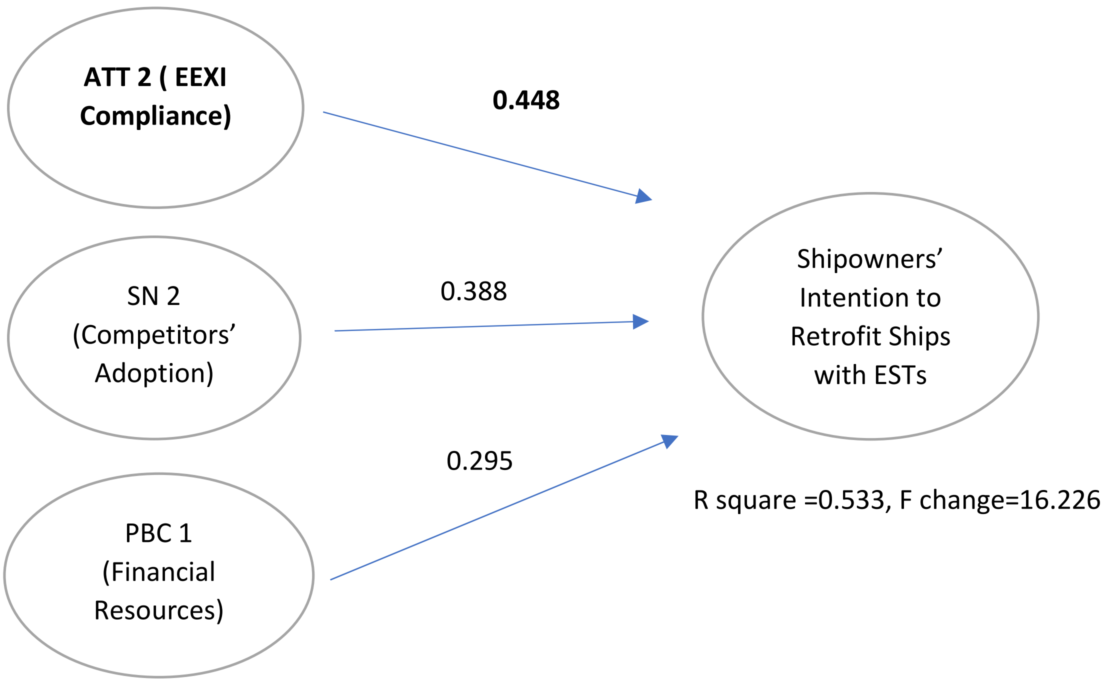

Figure 7: Path coefficient diagram

5.1.6 Other Results

The response to open-ended questions identifies four other crucial factors: CII results improvement, fuel cost reduction, clients' requirements, and right ship conditions.

For other attitude (ATT) related factors, **CII result improvement,** and **fuel cost reduction** are identified as two essential factors. 13 respondents have answered the open-ended question "other expected outcomes of adopting ESTs for ship retrofitting." 4 informants point out that a critical purpose for them to retrofit ships with ESTs is to improve CII results, another essential international ship energy efficiency index mentioned in chapter two. Seven respondents have noted that saving fuel costs is an important motivator for retrofitting ships with ESTs. The data indicate that CII results improvements and fuel cost reduction are two essential driving factors in shipowners' decision-making table when retrofitting ships with ESTs.

For other social norms (SN) related factors, **clients' requirement** is identified as crucial factor. Among 12 informants answering the open-ended question "other important stakeholders for the company to adopt ESTs for ship retrofitting," all have mentioned the factor of clients' requirements, and 7 of them have specifically mentioned **charterers'** requirements. The data shows that charterers' requirements are a crucial reason for shipowners to retrofit ships with ESTs. In addition, other clients, such as offshore or subsea contractors, submarine cable manufacturers, and Powerlink interconnector owners, could also play a role in driving shipowners to adopt ESTs in ship retrofitting.

For other perceived behavioral control (PBC) related factors, **right ship conditions** are identified as the most significant factor. Among 16 shipowners who have answered the open-ended question "other important factors that affect the ability of the company to adopt ESTs for ship retrofitting," 12 of them have mentioned the importance of right ship conditions, especially ship age and the match with specific ESTs. One informant has written: "Requirements/conditions have to be carefully assessed. Not all ESTs are for all vessels, and in some cases, an EST will not contribute significantly." In addition, other mentioned factors include project teams, human resources, and financial cost-benefits. Overall, the data shows right ship conditions (especially ship age and the match with specific ESTs) as the most considered factor by shipowners when assessing their ability to retrofit ships with ESTs.

5.1.6 Summary of Survey Findings

The survey is set out to answer the first sub-question: ***what are the key driving factors to retrofit ships with ESTs from shipowners' perspective?*** The findings are summarized in Table 5.11.

Table 5-11 Summary of survey results

Dimensions	Driving Factors	Hypotheses	Results
Attitude (ATT)	ATT1. Higher Market Competitiveness	H 1: Higher market competitiveness has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.	Rejected
	ATT2. Compliance with EEXI	H 2: Compliance with EEXI has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.	Supported
	Other ATT Factors	(Open-ended question)	CII Result Improvement; Fuel Cost Reduction
Subjective Norm (SN)	SN1. Governments' advocacy	H 3: Governments' advocacy has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.	Rejected
	SN2. Competitors' adoption	H 4: Competitors' adoption has a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.	Supported
	Other SN factors	(Open-ended question)	Clients' requirements
Perceived Behavioural Control (PBC)	PBC1. Financial resources	H 5: Financial resources have a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.	Supported
	PBC2. Knowledge and experience	H 6: Knowledge and experience have a positive relationship with shipowners' intention to adopt ESTs for ship retrofitting.	Rejected
	Other PBC factors	(Open-ended question)	Right ship conditions

The driving factors to retrofit ships with ESTs from the shipowners' perspective are organized into three dimensions: attitude (ATT), social norm (SN), and perceived behavioral control (PBC), based on the theoretical framework of the Theory of Planned Behavior.

In the dimension of attitude (ATT), the most significant driver is found as **EEXI compliance**, with CII results improvement and fuel cost reduction found as other vital factors, while higher market competitiveness is found as an insignificant factor.

Regarding the dimension of subjective norms (SN), **competitors' adoption** is found as an essential driving factor, with clients' requirements identified as another critical factor, while governments' advocacy, in general, is found as a weak factor.

In the dimension of perceived behavioral control (PBC), **financial resources** are found to be a driver for shipowners' adoption of ESTs for retrofitting. At the same time, knowledge and experience are found to be weak factors, and right ship conditions (especially ship age) are identified as another crucial driving factor.

Regarding right ship conditions, it is unclear what kind of conditions are "right" and facilities shipowners' adoption of ESTs for ship retrofitting. The following section shows the statistical analysis results of Clarkson's database to solve this piece of the puzzle.

5.2 Database Results

This section displays the statistical analysis results of 4275 ship profiles from Clarkson's database. It aims to answer the second sub-research question: ***What are the key ship conditions for shipowners' adoption of ESTs for ship retrofitting?***

5.2.1 Small Ship Age

As identified in the previous survey results, ship age is perceived by shipowners as a critical ship condition for ESTs adoption. Therefore, the ship ages of the 4275 ships adopted with ESTs are analyzed, and the results show that, in general, small ship age tends to be a favorable ship condition for ESTs adoption.

Table 5-12 Ages of ships adopted with ESTs

	N	Minimum	Maximum	Mean	Std. Deviation
Ship age (years old)	4275	48	1	9	5.174

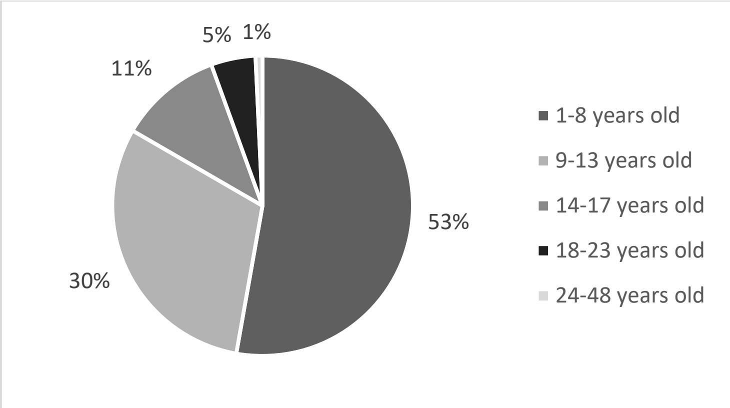

Figure 8: Ages of ships adopted with ESTs

As shown in Table 5.12 and Figure 8, over 80 percent of the ships adopted with ESTs are less than 13 years old, with the rest 20 percent ranging from 14 and 48 years old. This result suggests one of the right ship conditions for ESTs adoption is likely to be small ship age.

Table 5-13 Correlations between ship age and number of ESTs adoption

		Ship Age	Total ESTs	Propeller ESTs	Hull ESTs	Wind ESTs	Engine ESTs	Solar ESTs
Ship age	Pearson Correlation	1	-.219**	-.075**	-.132**	.045**	-.068**	-.039*
	Sig. (2-tailed)		<.001	<.001	<.001	.004	<.001	.011
	N	4275	4275	4275	4275	4275	4275	4275

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5.13 further examines the relations between ship age and the number of adoptions of different ESTs. Again, a significant negative relationship between ship age and the total number of ESTs adopted is found, which means the newer a ship, the more ESTs shipowners are likely to adopt on the ship in general. Concerning the different groups of ESTs, significant negative relations are found between ship age and the adoption of propeller ESTs, hull ESTs, engine ESTs, and solar ESTs. This indicates that the older a ship is, the condition for adopting the ESTs tends to be more unfavorable for these ESTs. Nevertheless, wind ESTs seem to be an exception. Overall, the results indicate small ship age as a critical ship condition for ESTs adoption in general.

5.2.2 Match with Specific ESTs

The gross tonnages (GT) of the 4275 ships adopted with ESTs are analyzed, and the results indicate that matching ships with specific ESTs is another key ship condition.

Table 5-14 Correlations between GT and number of ESTs adoption

		GT	Total ESTs	Propeller ESTs	Hull ESTs	Wind ESTs	Engine ESTs	Solar ESTs
GT	Pearson Correlation	1	.146**	.037*	-.088**	-.030*	.243**	-.043**
	Sig. (2-tailed)		<.001	.017	<.001	.049	<.001	.005

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

As shown in Table 5.14, the relations between GT and the number of ESTs adopted vary significantly in different groups of ESTs. For example, for propeller ESTs and engine ESTs, it appears that a bigger GT generally means more adoptions. In contrast, a smaller GT means more adoptions for hull ESTs, wind ESTs, and solar ESTs. This indicates that the different ESTs favor different ship sizes, and matching the ships with the preference of specific ESTs is the key to the adoption.

Indeed, ship size is just a tiny piece of the cake in terms of matching ships with specific ESTs, and there are various other aspects ranging from engine type to subtle technical issues. As revealed by shipowners in the survey results, matching ships with specific ESTs is crucial, and it requires rigorous ship testing managed by the technical departments of the shipping companies. This thesis omits technical details and grasps the central idea of matching ships with specific ESTs, with ship size elaborated as an example.

5.2.3 Summary of Database Findings

Section 5.2 presents the database results and aims to answer the second sub-research question: ***What are the key ship conditions for shipowners' adoption of ESTs for ship retrofitting?*** This study suggests that two key ship conditions are **small ship age** (less than 13 years old in general) and **the match with specific ESTs**.

5.3 Summary of Chapter V

Chapter V presents the empirical findings of the study and has answered the two sub-research questions in 5.1 and 5.2, respectively. This summary wraps up the findings and answers the main research question: **what drives shipowners' decision to adopt ESTs for ship retrofitting?** The drivers are summarized in Figure 9 in three dimensions based on the framework of the theory of planned behavior. First, regarding attitude-related drivers, compliance with EEXI is found to be the main driver for shipowners to adopt ESTs for ship retrofitting. Besides, improving CII results and reducing fuel costs are identified as the other two driving factors. Moving on to the dimension of social norm-related drivers, competitors' adoption and clients' requirements are found to be significant driving factors that motivate shipowners to retrofit ships with ESTs. Finally, as for perceived-control-related drivers, finance resources and the right ship conditions are essential for shipowners' adoption of ESTs for ship retrofitting. Furthermore, right ship conditions are found as small ship age and match with specific ESTs.

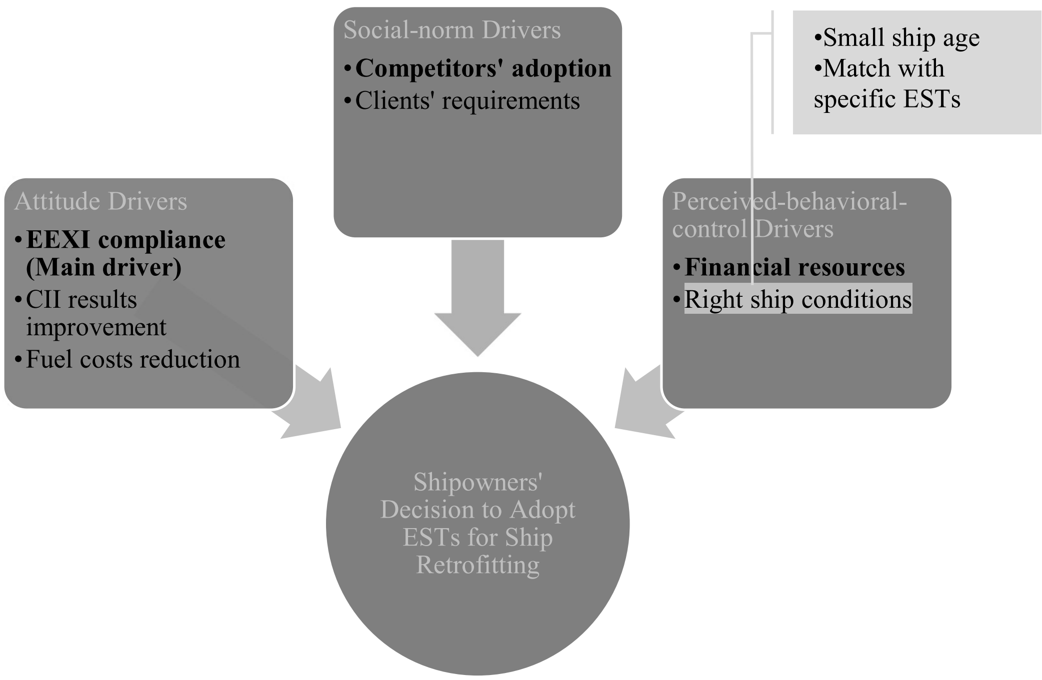

Figure 9: Summary of findings

Chapter VI: Discussion

This study aims to answer the main research question: ***What drives shipowners' decision to adopt ESTs for ship retrofitting?*** To achieve the purpose, the author surveyed shipowners that have adopted ESTs globally, applying the theory of planned behavior, and carried out a statistical analysis of all the profiles of ships with ESTs adoption in the World Fleet Register. The two main focuses of the study are:

(1) What are the key driving factors to retrofit ships with ESTs from shipowners' perspective?
(2) What are the key ship conditions for shipowners to retrofit ships with ESTs?

Based on the framework of the theory of planned behavior, the findings and the answer to the main research question are summarized in Figure 9 at the end of chapter five. This chapter further analyses the meaning of the findings, compare them with existing literature and identifies practical implications for policymakers and businesses.

6.1 Key Driving Factors to Retrofit ships with ESTs from Shipowners' Perspective

Regarding the first sub research question, "***What are the key driving factors to retrofit ships with ESTs from shipowners' perspective?",*** the findings suggest EEXI compliance, competitor's adoption, and financial resources are significant driving factors, while higher market competitiveness, governments' advocacy, and knowledge and experience are not. Moreover, other potential driving factors are identified as CII results improvement, fuel cost reduction, clients' requirements, and right ship conditions. This section further analyses and discusses the findings in the three theoretical dimensions of attitude, subjective norms, and perceived behavioral control.

To begin with, let us discuss the dimension of attitude. Compared to previous studies on green retrofit and ship energy efficiency, it agrees with existing literature that the new international energy efficiency indexes, especially EEXI and CII, would play the most significant role in driving shipowners' adoption of green technologies for ship retrofitting. With EEXI expected to be fully implemented in 2023, shipowners will have to invest in technical retrofit measures (Kaya & Erginer, 2021). This may be because shipowners must get the required EEXI technical file ready before EEXI takes effect, as explained in chapter two. If ships cannot meet the energy efficiency standards, this may disrupt the operation of the ships, for example, leading to shipping detain and fines.

Moreover, high market competitiveness is found as a weak factor. According to Kaya & Erginer (2021), technical retrofit measures are generally not financially attractive and feasible enough for shipowners. This may be because ship retrofitting, which could be costly and time-consuming, disrupts the regular operation of a ship, and competitors get more profits when ships from a shipowner's own company are being retrofitted with ESTs. Therefore, higher market competitiveness is not evident from this perspective.

In addition, fuel cost reduction is identified as a potential key driver, which conforms to previous studies. Fuel costs constitute around half of ship operating costs and play a significant role in the shipping industry (Han & Wang, 2021). For example, wind propulsion technology is expected to save fuel costs up to 20 percent, which could be attractive to shipowners (Talluri et al., 2018). Therefore, reducing fuel costs could be an essential factor in shaping shipowners' attitudes and intentions toward retrofitting ships with ESTs.

Moving on to the dimension of social norms, the finding agrees with existing research that competitors' adoption could be a key driving factor for shipowners to adopt ESTs for ship retrofitting. Hermann & Lin (2021) proposed the assumption that once competitors adopt, other shipowners would follow. This study appears to support the assumption. It is interesting to notice that higher market competitiveness is not an evident factor as discussed in the attitude dimension, while competitors' adoption appears to be. This may be because retrofitting ships with ESTs is not the most cost-effective way for a shipowner to increase market competitiveness by active choice, but once competitors adopt first, the rest could be pushed to keep up.

Moreover, in general, governmental advocacy is found as an insignificant factor, and there appears to be an interesting contrast with previous research on green retrofit. It was found that both local and national policies drive energy efficiency retrofitting projects in Brighton, UK (Martiskainen & Kivimaa, 2019). However, the finding by Martiskainen & Kivimaa (2019) is based on the construction industry, and the situation may differ from the shipping industry. Stevens et al. (2015) found that governmental regulations do not push shipowners to adopt technical retrofit measures in the first place and push them to buy ships with reduced speed instead. Technical retrofitting measures are not economically attractive to shipowners compared to operational measures (Kaya & Erginer, 2021), so government advocacy, in general, may not have a significant impact in front of practical cost-effectiveness issues. Nevertheless, a specific regulation item like EEXI is found to be a decisive factor, as discussed before, and this may be due to its potential coercive power (e.g., ships may not be allowed to operate if they do not conform to the ship energy efficiency index).

Finally, moving on to the dimension of perceived behavioral control, the finding indicates that financial resources are a key driver for shipowners' adoption of ESTs for ship retrofitting. This conforms to existing studies on green retrofit. In the field of residential housing retrofitting, it has been found that the three most critical decision-making factors are the payback period, the life-cycle cost, and the funding mechanism (Medal et al., 2020). Similarly, in ship retrofitting, funding is a critical factor for ship energy efficiency projects in the Danish maritime sector (Medal et al., 2020). Likewise, the investment cost and the payback period are essential factors for shipowners deciding whether to adopt energy efficiency measures on existing ships (Kaya & Erginer, 2021). The most significant barrier to adoption is assumed to be upfront retrofitting costs (Hermann & Lin, 2021). Therefore, financial resources could be a key enabler for shipowners' adoption of ESTs for ship retrofitting.

As for implications, the findings can be used to understand shipowners' behaviors concerning ESTs and the best ways to convince the shipowners to adopt the technologies. Here are practical recommendations for technology producers, governmental organizations, and other relevant parties who aim to promote energy efficiency improvement in shipping and the diffusion of energy-saving technologies.

Before anything, it is always best to communicate with a potential customer (shipowner) of the technologies to understand what goals they expect to achieve with the technologies and tailor the marketing strategy to the shipowner's specific needs. Nevertheless, here are some general pathways to follow:

First, this study suggests **providing supporting services** for compliance with international indexes (especially EXXI and CII) apart from technology installation. The international indexes are found to be the main driving factor and a common purpose for shipowners' decision to adopt ESTs for ship retrofitting. Therefore, one of the best ways to convince shipowners to adopt ESTs is to **emphasize how the technologies can help shipowners achieve better**

results with the indexes. Furthermore, supporting services for index results improvement apart from technology installation is expected to considerably increase the chance of a shipowner's adoption of the technologies.

Second, another best way is to **highlight the financial benefits of the technologies** to shipowners based on facts. Financial matters tend to be central to shipowners' decision-making table, especially those whose primary goal is to save fuel costs and make financial investments. This study suggests conducting a cost-benefit analysis of the technologies and clarifying costs, benefits, risks, and the payback period of technologies. It is essential to highlight the financial benefits of the technologies but also make clear other financial information.

Moreover, if it is hard for technology companies alone to make the technology financially attractive to shipowners, consider looking for **collaboration with governments to create extra financial incentives**. Here are concrete financial incentives for governments to consider, including but not limited to investment tax credits (ITCs) coupled with lending, which is found effective in sustainable retrofits (Brotman, 2017), green technology subsidies, energy efficiency grants, and financial services to offset risks.

In addition, **reaching out to shipowners whose competitors have adopted** is another option. Since competitors' adoption tend to have driving effects on others' adoption, the shipowners whose competitors have adopted are more likely to be high potential customers of green technologies. There are also other ways to identify shipowners with high technology adoption potential, discussed in the next section.

6.2 Key Ship Conditions for Shipowners to Retrofit Ships with ESTs

Regarding the second research question: ***what are the key ship conditions for shipowners to adopt ESTs for retrofitting?*** The findings show that small ship age and the match with ESTs are two key conditions.

This study suggests that new ships are more favorable for EST adoption than old ones in general, and this agrees with previous research. According to Kaya & Erginer (2021), when investing in energy efficiency measures, the service life of the ships is a significant factor, especially when it comes to payback. In general, it could be said that the high average age of the fleets could adversely affect investments in technical measures that bring high costs (Kaya & Erginer, 2021). Ships usually have a life cycle of 25 years (European Commission, 2011), and it is not cost-effective for shipowners to retrofit a ship that is about to retire in the near future.

The match with specific ESTs is found as another key ship condition for ESTs adoption in this study, and this appears to conform to existing literature. Depending on the characteristics of the measures, model tests, simulations, or data sets should be used to determine whether energy efficiency measures are compatible with the ship's technical specifications at the planning stage (Kaya & Erginer, 2021). This suggests that the match between a ship and specific ESTs must be carefully accessed for each ship, and this is a critical ship condition. Clearly, not any ESTs can be adopted on a ship to achieve energy efficiency improvement. For instance, as one technology of propeller optimization, propellers with contra-rotating blades require a short shaft line, so they can only primarily be matched with single-screw ships (IMO, 2011).

Here are practical implications of the findings for governmental organizations and businesses who aim to promote green retrofitting technologies to shipowners: **Identify high potential customers (shipowners) based on key ship conditions before head.** Some customers are naturally harder to persuade than others, and reaching the right shipowners could significantly improve the effectiveness and the efficiency of promoting the technologies. This research gives some concrete pathways to identify high potential customers.

One important way is through the ship age. As identified in the results chapter, ships between 9 and 13 are highly likely to be installed with ESTs. If targeting a shipowner whose ships are mostly either too old for retrofit or newly built eco-ships with high energy efficiency already, this is assumed to limit the success of promoting ESTs to the shipowner substantially. Instead, identifying shipowners who own a considerable number of ships with favorable ship age and other ship conditions and targeting them would be an effective way of promoting ESTs for ship retrofitting in general. A concrete and highly feasible way to do this is through **a further statistical analysis of all the ship profiles (approximately 55000) in the World Fleet Register** based on ship age and other ship conditions. This can identify a list of shipowners whose ships have a potential high need for ESTs in the future.

Furthermore, for businesses that produce a specific group of ESTs like wind technologies, the optimal range of ship age for shipowners' adoption may differ. In this case, information should be gathered from the company's technical department, including but not limited to suitable ship age, ship type, ship size, and other critical ship conditions for shipowners' adoption of the technologies. Then, based on the key ship conditions specific to the technologies, a statistical analysis of all the ship profiles in the World Fleet Register can still be run to identify a list of shipowners who have the likely highest need for the technologies. Then, along with other conditions like location, the list could be further narrowed down. In this way, a manageable list of reachable shipowners with the potential highest need for the technologies would be identified. Targeting these shipowners is expected to increase the success of promoting green technologies considerably.

6.3 Summary of Chapter VI

Chapter VI discusses the findings compared to previous studies and provides practical recommendations for businesses and governments to promote green technologies to shipowners.

The findings appear to conform to existing literature that international energy efficiency indexes (specifically EEXI and CII), competitors' adoption, and financial resources are three main drivers for shipowners' adoption of ESTs for ship retrofitting. At the same time, the finding that governmental advocacy, in general, is a weak factor for green retrofit with ESTs contradicts some previous research. This could be because the previous studies are based in the construction industry context, while this study focuses on shipping.

Four best ways are identified for green technology producers and governmental bodies to convince shipowners to adopt green technologies for ship retrofitting: (1) emphasize how the technologies can help shipowners achieve better results with international energy efficiency indexes, specially EEXI and CII, and provide support services for index compliance apart from technology installation. (2) highlight the financial benefits of the technologies to shipowners. If the technologies are not financially attractive, seek collaboration with governments to create extra financial incentives. (3) reach out to shipowners whose competitors have adopted the technologies. (4) identify high potential customers based on key ship conditions. Further statistical analysis of all the ship profiles (around 55000) in the World Fleet Register is proposed to list shipowners with high technology adoption potential.

Chapter VII: Conclusion

This chapter concludes the thesis by summarising the key findings concerning the research aim as well as the contribution thereof. It also reviews the limitations of the study and proposes opportunities for future research.

The study sets out to answer the main research question: ***What drives shipowners' decision to adopt ESTs for ship retrofitting?*** The results indicate that EEXI compliance, competitors' adoption, and financial resources are three main drivers for shipowners' adoption of ESTs for retrofitting. The findings also suggest that other key driving factors include better CII results, fuel cost reduction, clients' requirements, and right ship conditions. Further findings show that small ship age in general and match with specific ESTs are two key ship conditions that facilitate shipowners' adoption of ESTs for ship retrofitting.

The main contribution of this thesis has been to investigate the drivers of ESTs adoption for ship retrofitting with a focus on shipowners' perspective (precisely shipowners' motivation) and thoroughly assess the factors that motivate shipowners to retrofit vessels with ESTs. It has contributed to filling the research gap in the existing literature on green retrofit by focusing on the context of the global shipping industry. Moreover, it has added something new to the literature on the application of the theory of planned behavior with up-to-date empirical data in the maritime sector. Furthermore, the study can be useful for EST suppliers and regulation makers to understand the shipowners' behavior concerning technology acceptance and the best ways to promote green technologies to shipowners, which could accelerate energy efficiency improvement and green transition in the shipping industry.

One limitation of the study is a relatively small number of survey data for regression analysis and potential sample bias. First, due to the limited time span and difficulty of collecting many responses from managers in companies, the survey sample is not big for regression modeling,. However, this limitation is mitigated by a thorough statistical test of the sample and data assumptions. Second, there is potential sample bias due to possible significant differences between the survey respondents and non-respondents. Some survey recipients may be easier to reach than others in nature. To mitigate this limitation and capture a wide range of sample companies representing different opinions, companies of various sizes, locations, and types have been contacted. Moreover, the survey is made as short and easy to answer as possible, so it does not require much motivation to complete and encourages various recipients to answer.

Finally, another limitation of the study is the gap between motivation and actual behavior. As this research only investigates the motivation pieces of shipowners, the gap remains unexplored.

For further research, factors identified in the free-response survey questions of this study, including fuel cost reduction, client requirements, and right ship conditions, are recommended to be quantitively studied and put into a regression model in order to examine to what different degree the factors drive shipowners' adoption of ESTs. Besides, it would be interesting to conduct case studies on leading shipping companies in the maritime sector because they tend to influence the industry significantly. Another attractive further research area is to look at the differences between countries regarding the drivers of ESTs adoption. Different nations have different shipping regulations and standards, and a comparative study between countries would generate further insights.

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Appendix 1: Questionnaire (With Data)

1. In the past, my company has adopted energy-saving technologies (ESTs) for ship retrofitting.

	N	%
no	12	28.6%
yes	30	71.4%

2. I'm a decision-maker in my company.

	N	%
no	13	31.0%
yes	29	69.0%

3. My company's adopting ESTs for ship retrofitting will result in higher market competitiveness.

	N	%
1 strongly agree	7	16.7%
2 somewhat agree	14	33.3%
3 slightly agree	10	23.8%
4 neither agree nor disagree	2	4.8%
5 slightly disagree	1	2.4%
6 somewhat disagree	4	9.5%
7 strongly disagree	4	9.5%

4. My company's higher market competitiveness is

	N	%
1 extremely important	20	47.6%
2 quite important	10	23.8%
3 slightly important	4	9.5%
4 neither important nor unimportant	5	11.9%
5 quite unimportant	0	0%
6 slightly unimportant	2	4.8%
7 extremely unnecessary	1	2.4%

5. Adopting ESTs for ship retrofitting will help my company to comply with EEXI.

	N	%
1 strongly agree	12	28.6%
2 somewhat agree	11	26.2%
3 slightly agree	10	23.8%
4 neither agree nor disagree	5	11.9%
5 slightly disagree	1	2.4%
6 somewhat disagree	2	4.8%
7 strongly disagree	1	2.4%

6. For my company, complying with EEXI is

	N	%
1 extremely important	23	54.8%
2 quite important	10	23.8%
3 slightly important	6	14.3%
4 neither important nor unimportant	1	2.4%
5 slightly unimportant	1	2.4%
6 quite unimportant	0	0%
7 extremely unimportant	1	2.4%

Other expected outcomes of adopting ESTs for ship retrofitting

	N	%
Better CII results	1	2.4%
CII improvement	1	2.4%
Comply with CII	1	2.4%
Consumption saving	1	2.4%
Higher cost	1	2.4%
Improved CII results	1	2.4%
Less fuel cost	1	2.4%
Reduce fuel consumption	1	2.4%
Save fuel	2	4.8%
Save fuel cost	1	2.4%
Save fuel cost	1	2.4%
To meet energy efficiency standards	1	2.4%

7. Governments think my company should adopt ESTs for ship retrofitting.

	N	%
1 strongly agree	2	4.8%
2 somewhat agree	10	23.8%
3 slightly agree	12	28.6%
4 neither agree nor disagree	8	19.0%
5 slightly disagree	5	11.9%
6 somewhat disagree	3	7.1%
7 strongly disagree	2	4.8%

8. When it comes to adopting ESTs for ship retrofitting, how much does my company want to follow policies?

	N	%
1 very much	9	21.4%
2 somewhat	20	47.6%
3 slightly	9	21.4%
4 neither	3	7.1%
5 slightly not	0	0%
6 somewhat not	1	2.4%
7 not at all	0	0%

9. My competitor shipowners have adopted ESTs for ship retrofitting.

	N	%
1 completely true	2	4.8%
2 somewhat true	7	16.7%
3 slightly true	12	28.6%
4 neither true nor false	12	28.6%
5 slightly false	4	9.5%
6 somewhat false	3	7.1%
7 completely false	2	4.8%

10. When it comes to adopting ESTs for ship retrofitting, how much does my company want to keep up with other shipowners?

	N	%
1 very much	12	28.6%
2 somewhat	15	35.7%
3 slightly	8	19.0%
4 neither	4	9.5%
5 slightly not	2	4.8%
6 somewhat not	1	2.4%
7 not at all	0	0%

Other important stakeholders that influence my company's decision to adopt ESTs for ship retrofitting

	N	%
Charterer requirements	1	2.4%
Charterers and other clients	2	4.8%
Charterers	3	7.1%
Charterers, Right ship	1	2.4%
Client requirements	1	2.4%
Clients	3	7.1%
Clients, being other offshore/subsea contractors, submarine cable manufacturers, Powerlink interconnector owners, etc.	1	2.4%

11. My company expects to have financial resources to retrofit ships with ESTs.

	N	%
1 strongly agree	5	11.9%
2 somewhat agree	17	40.5%
3 slightly agree	12	28.6%
4 neither agree nor disagree	5	11.9%
5 slightly disagree	3	7.1%
6 somewhat disagree	0	0%
7 strongly disagree	0	0%

12. Having financial resources enables my company to adopt ESTs for ship retrofitting.

	N	%
1 strongly agree	20	47.6%
2 somewhat agree	15	35.7%
3 slightly agree	4	9.5%
4 neither agree nor disagree	3	7.1%
5 slightly disagree	0	0%
6 somewhat disagree	0	0%
7 strongly disagree	0	0%

13. My company expects to have knowledge and experience to retrofit ships with ESTs.

	N	%
1 strongly agree	13	31.0%
2 somewhat agree	18	42.9%
3 slightly agree	8	19.0%
4 neither agree nor disagree	2	4.8%
5 slightly disagree	1	2.4%
6 somewhat disagree	0	0%
7 strongly disagree	0	0%

14. Having knowledge and experience enables my company to retrofit ships with ESTs

	N	%
1 strongly agree	20	47.6%
2 somewhat agree	15	35.7%
3 slightly agree	5	11.9%
4 neither agree nor disagree	1	2.4%
5 slightly disagree	0	0%
6 somewhat disagree	1	2.4%
7 strongly disagree	0	0%

Other important factors that make it easy or difficult for my company to adopt ESTs for ship retrofitting

	N	%
A project team is a key to performing retrofits	1	2.4%
Age of ships and EST testing	1	2.4%
Age of the ship/ LCCA analysis	1	2.4%
Demonstrating the financial cost/benefit	1	2.4%
Financial risk	1	2.4%
Human resources	1	2.4%
Payback period and risks, vessel conditions	1	2.4%
Right ships and technologies	1	2.4%
Ship age, etc.	2	4.8%
Ship age	1	2.4%
Ship suitability, being ship age, etc.	1	2.4%
Technical issues like how well the technologies match the ships in my company.	1	2.4%
The design of vessels and operational requirements/conditions have to the carefully assessed, and not all ESTs are for all vessels, and in some cases, an EST will not contribute significantly.	1	2.4%
Vessel design	1	2.4%
Whether ships match ESTs	1	2.4%

15. My company's adopting ESTs for ship retrofitting before 2023 would be

	N	%
1 extremely desirable	3	7.1%
2 quite desirable	12	28.6%
3 slightly desirable	15	35.7%
4 neither desirable nor undesirable	6	14.3%
5 slightly undesirable	5	11.9%
6 quite undesirable	1	2.4%
7 extremely undesirable	0	0%

16. Most important stakeholders approve of or encourage my company to adopt ESTs for ship retrofitting before 2023.

	N	%
1 strongly agree	2	4.8%
2 somewhat agree	11	26.2%
3 slightly agree	15	35.7%
4 neither agree nor disagree	7	16.7%
5 slightly disagree	3	7.1%
6 somewhat disagree	3	7.1%
7 strongly disagree	1	2.4%

17. My company is confident in its ability to adopt ESTs for ship retrofitting before 2023.

	N	%
1 strongly agree	4	9.5%
2 somewhat agree	16	38.1%
3 slightly agree	13	31.0%
4 neither agree nor disagree	7	16.7%
5 slightly disagree	1	2.4%
6 somewhat disagree	1	2.4%
7 strongly disagree	0	0%

18. I can decide whether to retrofit ships with ESTs in my company.

	N	%
1 strongly agree	4	9.5%
2 somewhat agree	13	31.0%
3 slightly agree	10	23.8%
4 neither agree nor disagree	6	14.3%
5 slightly disagree	4	9.5%
6 somewhat disagree	1	2.4%
7 strongly disagree	4	9.5%

19. My company intends to adopt ESTs for ship retrofitting before 2023.

	N	%
1 strongly agree	1	2.4%
2 somewhat agree	8	19.0%
3 slightly agree	11	26.2%
4 neither agree nor disagree	8	19.0%
5 slightly disagree	3	7.1%
6 somewhat disagree	9	21.4%
7 strongly disagree	2	4.8%

Other comments

A technical department can decide and propose which ESTs are applicable/required. The decision comes from management after a review of the proposal.	1	2.4%